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THE NORTH CENTRAL STUDY AREA (NCSA) REPORT INTEGRATES THE STUDY AREA HISTORY, GEOLOGY, AND HYDROLOGY WITH THE RESULTS OF SOIL, SURFACE WATER, GROUND WATER, AIR, BIOTA, AND STRUCTURES INVESTIGATIONS TO DEFINE THE NATURE AND EXTENT OF CONTAMINATION OF THE CENTRAL AND NORTHERN AREAS OF RMA.

THE NCSA INCLUDES THE DISPOSAL BASINS, INTERCONNECTING DITCHES AND ADJOINING SITES, THE SEWER SYSTEMS, AND THE NORTH AND NORTHWEST BOUNDARY CONTAINMENT SYSTEMS. THE CHEMICAL SAMPLING PROGRAM INCLUDED ANALYSIS OF 2,186 SAMPLES FROM 965 BORES AND MONITORING OF OVER 230 WELLS AND 8 SURFACE WATER LOCATIONS. THE MOST WIDELY DISTRIBUTED CONTAMINANT GROUP IS ORGANOCHLORINE PESTICIDES. THE VOLUME OF POTENTIALLY CONTAMINATED SOIL IS ESTIMATED TO BE 9.2 MILLION CUBIC YARDS.

THIS REPORT IS PRESENTED IN THREE SECTIONS:

1. CHARACTERIZATION OF THE STUDY AREA - GEOLOGY, HYDROLOGY, CLIMATE, HISTORY

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VOLUME XI
NORTH CENTRAL STUDY AREA,
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PREPARED FOR:

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Standard Abbreviations Used in North Central Study Area Report

1. Analyte Groups and Selected Analytes

VHO -	Volatile halogenated organic compounds
VHC -	Volatile hydrocarbons
VAO -	Volatile aromatic organic compounds
OSCM -	Organosulfur compounds, mustard-agent related
OSCH -	Organosulfur compounds, herbicide related
OPHGB -	Organophosphorous compounds, GB-agent related
OPHP -	Organophosphorous compounds, pesticide related
DBCP -	Dibromochloropropane
DDE -	Dichlorodiphenylethane
DDT -	Dichlorodiphenyltrichloroethane
ONC -	Organonitrogen compounds
PAH -	Polynuclear aromatic hydrocarbons
SHO -	Semivolatile halogenated organic compounds
SVO -	Semivolatile organics
VO -	Volatile Organics
OCP -	Organochlorine pesticides
ICP METALS -	Metals analyzed for by inductively coupled argon plasma, includes cadmium, chromium, copper, lead, and zinc
GB -	Isopropylmethane-fluoro-phosphonate

2. National Acts & Organizations

CERCLA -	Comprehensive Environmental Response, Compensation, and Liability Act
NCP -	National Contingency Plan
NOAA -	National Oceanic and Atmospheric Administration
SARA -	Superfund Amendments and Reauthorization Act
USATHAMA -	United States Army Toxic and Hazardous Materials Agency
USAEWES -	United States Army Engineer Waterways Experiment Station
USDA-SCS	United States Department of Agriculture - Soil Conservation Service
USEPA -	United States Environmental Protection Agency
USFWS -	United States Fish and Wildlife Service

3. Local Terminology

BCRL -	Below Certified Reporting Limit
CAIS -	Chemical Agent Identification Sets
CAR -	Contamination Assessment Report
CDH -	Colorado Department of Health
CDOW -	Colorado Division of Wildlife
CRL -	Certified Reporting Limit
CSA -	Central Study Area
EA -	Endangerment Assessment
ESA -	Eastern Study Area
FS -	Feasibility Study
IRA -	Interim Response Action
NCSA -	North Central Study Area
NPCS -	North Plant Chemical Sewer
NPSA -	North Plant Study Area
PMO or PMRMA-	Program Managers Office for the RMA Contamination Cleanup
PM-10 -	Particulate matter 10 microns or less

QA -	Quality Assurance
RI -	Remedial Investigation
RIC -	Resource Information Center
RMA -	Rocky Mountain Arsenal
RMACCPMT -	Rocky Mountain Arsenal Contamination Cleanup Program Managers Team
SAR -	Study Area Peport
SCS -	Soil Conservation Service
SPSA -	South Plants Study Area
TEU _	U.S. Army Technical Escort Unit
TPP -	Technical Program Plan
TSP -	Total Suspended Particulates
UXO -	Unexploded Ordnance

4. Companies

CAPS -	Colorado Air Photo Service
EBASCO -	Ebasco Services Incorporated
ESE -	Hunter/Environmental Science & Engineering, Inc.
HLA -	Harding, Lawson, & Associates.
MKE -	Morrison-Knudsen Engineers, Inc.

5. Unified Soil Classification System (USCS) Textural Key

CL -	inorganic clay, low plasticity
GC -	clayey gravel
GP -	poorly graded gravel
ML -	inorganic silt, low plasticity
SC -	clayey sand
SM -	silty sand
SP -	poorly graded sand
SW -	well graded sand

6. Measurements

gpd -	gallons per day
mg/l -	milligrams per liter
mph -	miles per hour
msl -	mean sea level
ppm -	parts per million
ppb -	parts per billion
ug/g -	micrograms per gram, equivalent to parts per million (ppm)
ug/l -	micrograms per liter, nearly equivalent to parts per billion (ppb)
AA -	atomic absorption
CEC -	cation exchange capacities
CVAA -	cold vapor atomic absorption
Eh -	oxidation potential
GC/EC -	gas chromatography/electron capture
GC/MS -	gas chromatography/mass spectrometry
K_d -	soil - water partition coefficient
K_h -	Henry's law constant
K_{oc} -	organic carbon partition coefficient
K_{ow} -	octanol - water partition coefficient

REMEDIAL INVESTIGATION REPORT

VOLUME XI

NORTH CENTRAL STUDY AREA

EXECUTIVE SUMMARY

The North Central Study Area (NCSA) Report defines the nature and extent of potential contamination in the North Central portion of the Rocky Mountain Arsenal (RMA). The term "potential contamination" as used in this report refers to concentrations of contaminants at or above indicator levels. The use of the term "potential contamination" as opposed to simply "contamination" is intended to reflect the distinction that ultimately will be drawn between the presence of "contamination" at or above indicator levels and the presence of "contamination" at levels requiring remediation, i.e., concentrations of contaminants in excess of "action levels" as determined and established through applicable, or relevant and appropriate requirements (ARARs) and the Endangerment Assessment. Whereas all contamination at or above indicator levels, i.e., "potential contamination" was investigated during the Remedial Investigation and reported in the Contamination Assessment Reports (CARs) and the Study Area Reports (SARs), only contamination in excess of "action levels," i.e., "actual contamination" will drive the Feasibility Study.

This report integrates historic information with the results of previous investigations and the Remedial Investigation (RI) of soil, surface water, groundwater, air, biota, and structures. In general this report summarizes information and data presented previously in Contamination Assessment Reports (CARs) and Phase II Data Addendum reports, which are subproducts of the RI.

A detailed presentation of the Quality Assurance/Quality Control (QA/QC) Program utilized in the RI is given in the volume entitled "Introduction to the CARs." Evaluations of QA/QC procedures with respect to specific data are presented in the individual CAR and Phase II Data Addendum reports. Neither has been reproduced in this report.

The NCSA encompasses the primary aqueous waste disposal systems that served the South Plants and North Plants facilities at RMA. The main areas investigated were the unlined basins (A, B, C, D, and E) and the interconnecting ditches and adjoining sites, Basin F and the surrounding area, the chemical sewer system, the sanitary waste disposal system, and the North and Northwest Boundary Containment Systems. Regional studies were also performed in potential nonsource areas away from recognized disposal sites or developed areas. In addition to the NCSA sites identified in this report, the study area may have been affected by sites in adjoining study areas, specifically the Central Study Area (CSA) and the South Plants Study Area (SPSA).

Reviews of aerial photographs, historical documents, operating records, facility drawings, and interviews with RMA personnel were used to reconstruct the history of the NCSA. This history included the transport and disposal of aqueous waste from Army agent manufacturing and demilitarization activities, nonagent munitions manufacturing and demilitarization, and pesticide and herbicide production. Potential contaminants identified in the wastestreams generated by these activities include, but were not limited to, volatile halogenated solvents and volatile aromatic solvents, volatile hydrocarbons, mustard-agent related organosulfur compounds, herbicide related organosulfur compounds, GB-agent related organic compounds, organochlorine pesticides and pesticide-related compounds, arsenic, mercury, and ICP metals.

The hydrogeologic environment, air, and biota of the NCSA were monitored during the RI to detect the presence of contaminant sources and to assess the migration pathways and receptors of those contaminants. The RI included study of NCSA soils, the geology of the alluvium, and the underlying Denver Formation bedrock. The hydrology of these units and of surface water in the NCSA were also assessed. Structures and biota were inventoried, and climatic characteristics were evaluated.

RI sampling for chemical analyses in the NCSA to detect potential contaminant sources in soils from the surface through the vadose zone to the water table included the collection of 2,186 soil samples from 965 borehole or grab sample locations. In addition, surface water samples were collected seasonally from eight locations. The alluvial, unconfined and confined Denver Formation wells were sampled to assess distribution of potential contaminants in groundwater and define migration pathways. Analytical results from April to June 1987 sampling of 233 alluvial and Denver Formation monitoring wells are presented in this report supplemented by data from RI wells installed and sampled in Spring 1988 and Winter 1989. Air and biota monitoring were conducted in the NCSA on a regional scale and at site-specific locations. These RI data and the results of previous and off-post studies were integrated to identify source areas and migration pathways and to assess the potential exposure of receptors to contaminants.

Several sites in the NCSA were identified as sources of volatile halogenated organics; volatile hydrocarbons; volatile aromatic organics; organosulfur compounds, Mustard-Agent related; organosulfur compounds, herbicide related; organophosphorous compounds, GB-agent related; DBCP; fluoroacetic acid; semivolatile halogenated organics; polynuclear aromatic hydrocarbons; organochlorine pesticides; arsenic; mercury; and ICP metals to vadose zone soils. These potential contaminants were found at varying concentrations in the soils beneath the unlined basins and interconnecting ditches, the chemical sewers, and Basin F and the surrounding area. Minor occurrences of organic compounds and metals of limited extent and at relatively low concentrations were also detected in the North Bog, the sanitary sewer system, and nonsource areas of Sections 23, 24, 25, 26, 27, 35, and 36. The most widely distributed compound group detected was the organochlorine pesticides, which are considered to be the most environmentally persistent of the organic compounds detected at RMA. Other potential contaminants widespread in NCSA soils include arsenic, mercury, and GB-agent related organophosphorous compounds. The other potential contaminant groups mentioned above were generally found in recognized disposal sites. Some detections were at high concentrations, but occurrences were sporadic or limited to discrete sites. Generally the soils in recognized disposal sites contain both organic and inorganic analytes. The total volume of NCSA soils potentially contaminated by organic compounds has been estimated at 6,700,000 yds^3. The total volume of NCSA soils potentially contaminated by inorganic analytes has been estimated at 2,500,000 yds^3. These volume estimates will be subject to revision pending determination of action levels. Assumptions used to calculate these volumes are explained in Section 3.4.

The main migration pathways of potential contaminants in the NCSA were found to be in vadose zone soils and in the groundwater. Minor migration pathways have been identified in air and biota. The sites identified as sources of potential contaminants to groundwater include the unlined basins and interconnecting ditches, Basin F, and the immediate Basin F exterior.

In the unconfined aquifer system, groundwater plumes were identified for volatile halogenated organics, dicyclopentadiene, volatile aromatics, mustard-agent related organosulfur compounds, herbicide related organosulfur compounds, GB-agent related organophosphorous compounds, DBCP, dieldrin, and arsenic. These plumes were generally contained within two major pathways, the Basin A Neck pathway, and the Basin F and Basin F east pathway. Potential contaminants traveling along the Basin A Neck pathway can extend as far as the RMA border in Section 22 where they are intercepted by the Northwest Boundary Containment System. The North Boundary Containment System intercepts and treats potential contaminants traveling along the Basin F and Basin F east pathway. The North Boundary Containment System appears to effectively prevent off-post migration of potential contaminants in the unconfined aquifer. The Northwest Boundary Containment System is partially effective; chloroform has been detected in the treatment system effluent. The confined aquifers of the Denver Formation were found to contain many of the same contaminants detected in alluvial and unconfined Denver Formation wells, but concentrations were generally much lower and areal extents appear to be limited.

The surficial soils in the Basin A area and the other unlined basins appear to be sources of potential contaminants to vertebrate and invertebrate biota and vegetation. Sunflower samples from Basin C were found to contain organochlorine pesticides, whereas sunflowers from Basin A contained arsenic.

Organochlorine pesticides, arsenic, and mercury were also detected in the tissues of grasshoppers, birds, and rabbits collected from these areas.

Basin A and Basin F have also been identified as possible sources of airborne contaminants. Volatile halogenated organics, herbicide related organosulfur compounds, and organochlorine pesticides were detected during air monitoring downwind of Basin F, and herbicide related organosulfur compounds and organochlorine pesticides were detected downwind of Basin A. Deposition of windborne contaminants from Basin F and from spraying activities in the Basin F area have apparently affected the surficial soils in the area immediately surrounding the basin. Windborne deposition may also have affected surficial soils south of Basin A.

With the exception of the "Surficial Soil Program", the term "surficial soil" as used in this report is equivalent to "shallow soil", and refers to that portion of the soil profile extending from the ground surface to a depth of 12 inches. The "Surficial Soil Program" is a specific investigation of the zero to two inch depth interval, to be conducted as part of the Feasibility Study.

The RI was conducted before the Interim Response Actions (IRAs) were implemented. The IRAs were designed to mitigate major active sources of potential contaminants to migration pathways. The Basin F IRA was completed in spring 1989. This action involved removal and containment of the impounded fluids, excavation and solidification of the overburden/sludge, liner, and some of the underlying soil, storage of this material in a lined waste pile, and coverage of the entire Basin F area and waste pile with a low permeability clay cap and topsoil. At completion, Basin F should no longer be considered a source to air, or groundwater via infiltrating fluids. Other IRAs performed in the NCSA include, but are not limited to, spraying the Basin A area with an inert organic dust suppressant (which should eliminate this site as a source of windborne contaminants) and the installation of recharge trenches downgradient of the North Boundary Containment System.

The comments of the Organizations and State (the parties), and the responses of the Army, are appended to and constitute an integral part of this report. In order to gain a complete understanding of this document, the reader's attention is directed to these appendices.

1.0 STUDY AREA CHARACTERIZATION

This section presents the physiographic and climatic characteristics of the North Central Study Area (NCSA), discusses the scope of this report (including a summary of historic and remedial investigations), and summarizes the history of structures and activities related to areas of potential contamination in the NCSA. Finally, the geology, hydrology, and biota of this study area are discussed in detail sufficient to assess contamination and initiate the evaluation of Remedial Action Alternatives (RAAs).

1.1 PURPOSE AND SCOPE OF REPORT

The purpose of the NCSAR is to present a summary of the results of the Army's Remedial Investigation (RI) of the north-central portion of the Rocky Mountain Arsenal (RMA). This document is a formal RI Product, in accordance with the Proposed Consent Decree (1988), the Federal Facility Agreement (1989), the Settlement Agreement (1989), the RMA Technical Program Plan (TPP) (PMO, 1988/RIC 88131R01), and the June 1985 RI Guidance Document (EPA). The seven completed RI Study Area Reports, along with the RI media reports for air, biota, buildings, and water, fulfill the requirements for defining the nature and extent of contamination and completing a comprehensive remedial investigation for the On-post Operable Unit of RMA as required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act (SARA), and the National Contingency Plan (NCP). The NCSAR integrates known historical information, the results of previous investigations, and the current RI programs for soil, surface water, and groundwater to present an overall environmental contamination assessment of the study area as required under contract number DAAA15-88-D-0024. The NCSAR represents Volume XI of the overall RMA RI.

The NCSAR summarized part of the RI conducted by the U.S. Army Program Manager's Office for RMA Contamination Cleanup (PMO). Because the RI was carried out over a diverse area and consists of many elements, the results are presented in an overview volume, four media reports (water, air, biota, and structures), and seven geographical study area reports. The twelve reports are listed on Table NCSA 1.1-1. These 12 reports will represent the final RI products in the overall Remedial Investigation/Feasibility Study (RI/FS) as outlined in the RMA Technical Program Plan (TPP). The Endangerment Assessment (EA) and Feasibility Study (FS) will rely on the seven study area reports, the four media reports, the site-specific Contamination Assessment Reports (CARs), and the USATHAMA database when evaluating remedial alternatives.

This report, Volume XI, relates the usage history, geology, and hydrology of the NCSA to chemical analytical results from air, biota, soil, surface, and groundwater samples collected from the study area. Collectively, this information is used to characterize the contamination present and to aid in designing an effective cleanup program. Topics addressed in this report include the geology and hydrology of the NCSA, areas where contaminants have been detected, patterns of contaminant distribution, contaminant migration pathways, and receptors of contamination. The report also presents a discussion of the previous investigations pertaining to the NCSA and a summary of investigations performed during the RI by PMO contractor teams. The final section of this report summarizes interpretations of contaminant distribution and migration.

1.1.1 Summary of Previous Investigations

Several site-specific and RMA-wide investigations have been conducted at RMA. Hydrologic, geologic, and contaminant studies were conducted throughout RMA from 1975 until 1984 when the RMA Decontamination Report (RMACCPMT, 1984/RIC84034R01) was developed by the Army for planning purposes. The RMACCPMT report identified and classified over 150 potential contaminant sites at RMA and provided a preliminary assessment of the extent, probable use, boundaries, and possible contamination profile of each of these sites. Table NCSA 1.1-2 presents a summary of the most significant programs and investigations conducted prior to the current RI, which began in 1984.

The sites identified by the RMACCPMT were presented on a RMA-wide map that has become known as the "tricolor" map due to its use of three colors (pink, yellow, and blue) to graphically represent the likelihood of the site being an actual contamination source. These potential sources were delineated to concentrate the RI/FS on areas where contamination was most likely to be found. In addition, investigations were conducted in nonsource areas (i.e., those portions of RMA where there was no previous indication of potential contamination).

1.1.2 Summary of Remedial Investigations

RI tasks were designed to define the nature and extent of contamination on RMA to a degree sufficient to permit an assessment and selection of viable cleanup operations. Contractor teams conducted extensive air, biota, buildings, water, and soil/sewer investigations. Results of the air, biota, and building investigations are presented in separate reports and are summarized in the Study Area Reports. Results of the soil and groundwater investigations for each study area are discussed in the respective Study Area Reports.

The results of investigations performed under separate contracts by ESE and Ebasco and comprising Tasks 1, 4, 6, 7, 10, 14, 19, 20, 21, 25, 36, and 44 form the bulk of the data used in the preparation of the North Central Study Area Report. A description of each task and the area covered is provided below.

- Task 1 - Section 36. This task involved the development and execution of Phase I and Phase II soil remedial investigations for most sites within Section 36. The Phase II program of this task also involved installation of six groundwater monitoring wells in Section 36. Data collected during this task were used to define the nature and extent of contamination. NCSA areas investigated under this task include Sites 36-1, 36-4, 36-5, 36-7, 36-8, 36-10, 36-11, 36-13, 36-14, 36-15, 36-18, 36-20S, 36-21, 36-22, and a portion of Section 36 Nonsource Area (Plate NCSA 1.1-1).

- Task 4 - On-post Regional Water Monitoring Program. Task 4 covered regional on-post monitoring well sampling for the period between October

1985 and September 1986. It included initial sampling of 320 on-post wells between October 1985 and March 1986 and two additional quarters of sampling (April through June 1986 and July through September 1986) from 188 wells. Results of the initial 320 samples were presented in the Initial Screening Program Report; results from the two other quarterly sampling periods are presented in the Final Screening Program Report; and all results from all three sampling periods are presented in the Final Task 4 Report, (ESE, 1987n/RIC 88253R01). Regional sampling after September 1986 was assumed under Task 44 beginning in March 1987.

- Task 6 - Basins Area, Phase I. This task consisted of the development and execution of a Phase I soil and sediments remedial investigation for basins and drainage ditches within Sections 26 and 35. The investigation provided site-specific physical and chemical information on which to base the development of Phase II surveys. Areas within the NCSA investigated under Task 6 included Sites 26-1, 26-3, 26-4, 26-5, 26-6, 35-3, 35-4/26-7, and nonsource areas of Sections 26 and 35.

- Task 7 - Lower Lakes, Phase I. This task consisted of the development and execution of a Phase I soil and sediments remedial investigation for most of the lower lakes area. NCSA Sites 24-6 and 24-7 were also investigated under this task.

- Task 10 - Sewers Investigation. This task consisted of an assessment of soil contamination surrounding the RMA chemical and sanitary sewers and process water systems. NCSA Sites 24-5, 25-2, 26-8, 34-2, 35-1, and 36-20N were investigated under this task.

- Task 14 - Army Sites North, Phase I. This task entailed the development and execution of a Phase I soil remedial investigation for sites within the northern tier of RMA. The investigation provided site-specific physical and chemical information on which to base the development of Phase II surveys. Sites within the NCSA investigated under Task 14 included 35-2/26-9, 35-6, 35-7, and the nonsource areas of Sections 22, 23, 24, 25, 26, 27, 28, 34, and 35.

- Task 19 - Basins Area, Phase II. This task consisted of continuing investigations of areas initially investigated under Task 6 as deemed necessary after review of Phase I results and also included the installation of seven groundwater monitoring wells. Data resulting from this investigation were used to further define the extent of contamination present at each site.

- Task 20 - Lakes Area, Phase II. This task consisted of continuing investigations of sites and sections initially investigated under Task 7 as deemed necessary after review of the Phase I results. Data resulting from this investigation were used to further define the extent of contamination present at each site.

- Task 21 - Army Sites North, Phase II. This task consisted of continuing investigations of sites and sections initially investigated under Task 14 as deemed necessary after review of the Phase I results. Data resulting from this investigation were used to further define the extent of contamination present at each site.

- Task 25 - North and Northwest Boundary Containment System Monitoring. Task 25 was designed to provide additional groundwater quality monitoring coverage both upgradient and downgradient of the North Boundary Containment System (NBCS) and the Northwest Boundary Containment System (NWBCS) in order to collect the necessary data to evaluate the effectiveness of each system. Task 25 included monitor well installation and groundwater sampling over these areas on a quarterly basis during the period from September to December 1987.

- Task 36 - North Boundary System Component Remedial Action Assessment. The major objective of Task 36 was to evaluate the physical configuration and operational effectiveness of the NBCS. Items investigated as part of the task included the physical integrity of the bentonite barrier, the configuration of the Denver sand units in the vicinity of the system, alternatives for improving recharge capacity, and the adequacy of the current treatment components at removing all RMA related contaminants from the water.

- o <u>Task 44 - RMA Regional Groundwater/Surface Water Monitoring Program</u>. Task 44 was a continuation of the RMA regional (on-post and off-post) groundwater/surface water monitoring program covering the period between March and December 1987. Task 44 included an overall assessment of RMA-wide geology, geohydrology, and water quality and represented the final work product for the groundwater/surface water remedial investigation.

A list of the RI reports pertinent to the NCSA is provided in Table NCSA 1.1-3.

Soil investigations conducted under Tasks 1, 6, 7, 10, 14, 19, 20, and 21 were designed to address specific sites where possible contamination had occurred and to identify possible sites not previously documented. Techniques used in the Phase I and Phase II soil investigations included extensive review of historical documents and aerial photographs, soil and sediment sampling, detailed geophysical exploration, excavation and trenching, and chemical analyses of soil and sediment samples. The Phase I and Phase II investigations performed in the NCSA resulted in a total of 620 Phase I soil borings and 345 Phase II soil borings, yielding 1,072 Phase I soil samples and 1,114 Phase II soil samples.

Groundwater sampling was performed Arsenal-wide during the RI under Tasks 4, 25, 36, and 44. In addition numerous groundwater monitoring wells were installed under Tasks 1, 19, 21, 25 and 44 to improve coverage of the on-post area. Off-post sampling was conducted under Tasks 38 and 39. Groundwater data presented in Section 2 of this report were obtained during the spring 1987 sampling event, which is considered to be the most comprehensive single sampling episode performed. These data are supplemented by data from wells installed under Tasks 1, 19, 25, and 44 and sampled in Spring 1988, and by data from five RIFS2 wells installed and sampled in Winter 1989. The Spring 1987 period was selected because of both the comprehensive nature of the data set and the desirability of utilizing a data set for which temporal conditions or comparable and spatial comparisons were valid. One hundred thirty-nine alluvial and 94 Denver Formation monitoring wells were sampled in the NCSA during this period. Twenty-three wells were installed and sampled in the NCSA under Tasks 1, 19, 25, and 44. Five wells were installed and sampled in the NCSA under RIFS2.

Not all sites originally designated by the RMACCPMT or identified during the initial stages of the RI were found to contain contaminants. Those sites warranting further investigations under Phase II and all sites warranting further consideration after the initial screening evaluations conducted during the RI have been grouped by location and disposal history and renumbered for discussion purposes in this report. Table NCSA 1.1-4 lists the revised NCSA sites investigated under Phase II, and the original RMACCPMT potentially contaminated site designations. Plate NCSA 1.1-2 presents the revised NCSA site boundaries. Phase I and II soil boring locations in the NCSA are shown on Plate NCSA 1.1-3, and well locations are presented on Plate NCSA 1.1-4. General descriptions and the sites included within each of the eight site groupings are provided below.

1.1.2.1 NCSA-1 - Basin A and Adjoining Sites

This area incorporates all sites in Section 36 contiguous with or part of the Basin A aqueous waste disposal network, including: Basin A proper (NCSA-1a), the lime settling basins area (NCSA-1b), and the drainage ditches (NCSA-1c). These features were repositories for aqueous waste from the South Plants and North Plants and channeled Basin A overflow into the unlined basins in Section 35 and 26. Also part of this area are the liquid storage pool (NCSA-1d), which was used to retain storm runoff from South Plants, the burning site within Basin A, (NCSA-1e), and drainage ditches (NCSA-1f) east and west of Basin A, which carried storm runoff from the South Plants into Section 36.

1.1.2.2 NCSA-2 - Basins C, D, E and Related Ditches

These unlined basins were originally natural depressions in Section 26 modified to receive and retain aqueous wastes overflowing Basin B and/or flowing directly from South Plants via the Sand Creek Lateral. In its final configuration, Basin C (NCSA-2a) received flows from the Sand Creek Lateral and overflow from Basin B (NCSA-5a), which was subsequently channeled to

Basin D (NCSA-2b) along two short ditches (NCSA-2d) and then to Basin E (NCSA-2c).

1.1.2.3 NCSA-3 - Basin F

Basin F (NCSA-3) was a retention pond lined with catalytically-blown asphalt, which was constructed to replace the unlined basin network as the primary aqueous waste disposal facility at RMA. Waste streams from South Plants and North Plants were directed to Basin F by underground chemical sewers. The Interim Reponse Action undertaken at Basin F beginning in spring 1988 substantially altered the character of this site. Liquids were drained from the basin and stored in specially constructed tanks and a lined temporary impoundment area (called Pond A), soils were consolidated into a pile isolated from its surroundings by impermeable liners and coverings, and the basin area was capped and sealed.

1.1.2.4 NCSA-4 - Basin F Exterior

This area includes the deep disposal well system and associated treatment facilities and sewer lines (NCSA-4a) and the previously designated nonsource areas of Section 26 and 23, which apparently were affected by wind-borne contaminants from Basin F (NCSA-4b). The deep disposal well system was employed for several years to inject Basin F fluids into basement rock at a depth of approximately 12,000 feet (ft).

1.1.2.5 NCSA-5 - Basin B and Section 35 Aqueous Waste Disposal Ditches

Basin B (NCSA-5a) is a natural depression in Section 35 and was the original overflow receptacle serving Basin A. This area includes several generations of ditches dug to connect Basin A to Basin B, and Basin B to Basins C or D (NCSA-5b), the Sand Creek Lateral (NCSA-5c), and a drainage ditch dug to direct South Plants runoff away from Basin A and eventually into Section 34 (NCSA-5d).

1.1.2.6 NCSA-6 - Chemical Sewers

This area includes the underground sewer lines installed to transport aqueous wastes from South Plants (NCSA-6a) and North Plants (NCSA-6b) to Basin F. The sewer lines leading from South Plants through Sections 36, 35, and 26 were removed in 1982, and the line from North Plants was plugged at the junction with the South Plants line. The total area encompassed by NCSA-6 extends for 10 ft from either side along the traces of the underground sewer lines.

1.1.2.7 NCSA-7 - North and Northwest Boundary Containment Systems, and the North Bog

The NBCS and NWBCS were installed along the RMA borders in Sections 23 and 24, and 22 to intercept and treat contaminated groundwater migrating off-post. The North Bog (NCSA-7), a natural depression in Section 24 that collects surface and groundwater, has been included with these sites because it has been used since 1982 as a groundwater recharge basin for excess treated water from the NBCS. Since Fall 1988 most effluent from the NBCS has been directed to newly-constructed recharge trenches and effluent discharge to the North Bog has been decreased.

1.1.2.8 NCSA-8 - Sanitary Sewer

The sanitary sewer lines (NCSA-8a) extend from the railyard in Sections 3 and 4, the administration and barracks areas in Sections 35 and 34, the South Plants complex in Sections 1 and 2, and North Plants in Section 25 through Sections 34, 35, 36, 26, and 25 into Section 24 and terminate at the sewage treatment plant (NCSA-8b). The total area encompassed by NCSA-8 extends for 5 ft from either side of the sewer lines along their length and includes the area comprising the sewage treatment plant.

1.1.2.9 Balance of Areas Investigated

Table NCSA 1.1-4 lists several sites or areas that were addressed during the RI but have not been delineated within site groupings or for which no site number has been designated. Phase I RI results indicated that former Sites 36-5, 36-10, 36-14, and some areas of Section 36 originally designated as nonsource areas should be included as parts of Basin A or the lime settling basins. Former Sites 36-7, 36-13, 36-18, and 36-22 were found to be uncontaminated and were included as nonsource areas of Section 36. Similarly, former Sites 35-6 and 35-7 were also found to be uncontaminated and were included in Section 35 nonsource areas. In addition, designated nonsource areas in Sections 22, 23, 24, 25, 26, 27, 28, 34, 35, and 36, which were investigated during Phase I and Phase II of the RI and were found to be uncontaminated, were not incorporated into site groupings. Section 1.3 includes descriptions of the overall history of the NCSA and explains in detail the histories of the individual sites/areas of concern.

1.2 LOCATION, PHYSIOGRAPHY, AND CLIMATE

The NCSA, occupying nearly one-quarter of the total 27 square mile area encompassed by Rocky Mountain Arsenal, is one of seven study areas established to facilitate the interpretation and presentation of results from the RMA RI (Figure NCSA 1.2-1). Within the NCSA are the basins, sewer lines, and other facilities used by the Army and lessees for aqueous waste transport and disposal, as well as several other sites used by the Army for various operations.

The NCSA is located in the north-central part of RMA and occupies all or part of Sections 22, 23, 24, 25, 26, 27, 28, 34, 35, and 36. The NCSA encompasses a total area of approximately 6.7 square miles or 4,300 acres (Plate NCSA 1.1-2). The NCSA is bordered on the northwest and north by Commerce City, on the east by the North Plants complex and Central and Eastern Study Areas, on the south by the South Plants Study Area, and on the southwest by the Western Study Area. The portion of First Creek that crosses the northeast corner of Section 24 and the abandoned barracks, apartments, recreation, and storage areas in the southeast corner of Section 34 are excluded from the NCSA. These features are being addressed as part of the Eastern Study Area and the Western Study Area, respectively. The North Central Study Area Boundary was developed to incorporate areas used primarily for aqueous waste disposal at RMA.

The NCSA boundaries are generally well defined, either by the boundaries of the RMA, section lines that are demarcated by paved or unpaved roads, or distinct physical barriers such as the fence that surrounds the North Plants Study Area. The boundary between the NCSA and the CSA, however, is less distinct and generally corresponds to the high water line of Basin A (approximately 5,240 ft above mean sea level, msl). The CSA and NCSA will overlap to some degree in this region to ensure complete coverage of the activities associated with this portion of RMA.

The NCSA has a gently rolling topography, which generally slopes to the north-northwest with a topographic relief of approximately 170 ft (Plate NCSA 1.2-1). The topographic high is at an elevation of 5,300 ft msl at the top of Rattlesnake Hill in the central part of Section 35; the topographic low is in the northwest corner of Section 27 and the south-central part of Section 22 at an elevation of 5,125 ft msl. The Sand Creek Lateral traverses the study area from the southwest corner of Section 35 to the northeast corner of Section 25, where it eventually drains into First Creek. The surface drainage canal starts in the southwest corner of Section 36, extends through Section 35, and terminates at the northeast corner of Section 34. Several miscellaneous drainages occur within the study area and are associated with either the basin system in Sections 26, 35, and 36 or with the sewage treatment plant in Section 24.

The climate of RMA characteristically has low relative humidity, abundant sunshine, relatively light rainfall, moderate to high wind, and a wide daily range in temperature. The mean maximum temperatures range from 43°F in January to 88°F in July. The mean minimum temperatures are 16°F in January and 59°F in July. On the average, the diurnal fluctuation is about 28°F.

Precipitation in the vicinity of RMA is approximately 15 inches per year, with about half of the precipitation falling between April and July. Snow usually occurs from September to May, with the heaviest snowfall in March and possible accumulations as late as June. Thunderstorms occur frequently in the region, particularly during the spring and summer. There may be severe winds and occasional hail. The combined potential evaporation and transpiration rate ranges from 24 to 30 inches per year (NOAA, 1988).

The prevailing winds at RMA are from the south and south-southwest. Wind speeds average about 9 miles per hour (mph) (Figure NCSA 1.2-2). Occasionally, winds are from virtually all other directions. The windiest months are March and April, with gusts as high as 65 mph. These months follow the driest months of the year (November through February) and consequently have the highest potential for dust storms.

Tornados develop during proper frontal action and convective instability commonly associated with intense thunderstorms in the RMA area. Several work trailers and buildings at RMA were damaged by tornados in the summer of 1986. Several small tornados touched down at RMA in June 1988.

Occasionally during the winter, a meteorological phenomenon known as the Chinook winds crosses the eastern slope of the state from the southwest. These high intensity winds bring sudden temperature rises of as much as 20° to $35^{\circ}F$ within a few hours. Chinook winds greatly moderate average winter temperatures in the RMA vicinity.

Structures erected in the NCSA are listed in Table NCSA 1.2-1. All structures in the NCSA and RMA-wide have been inventoried and assessed and are discussed and shown in detail in the Structures Assessment (Ebasco, 19881/RIC 88306R02).

1.3 HISTORY

The following historical overview of the NCSA summarizes significant historical events revealed from aerial photographs, operating records, facilities drawings, and information taken from depositions that were contained within the Shell and Juris databases of former key employees and retired personnel.

1.3.1 Pre-RMA Use of the Study Area

Before the Army acquired the sections encompassing the NCSA, the entire area had been parcelled out to homesteaders. Aerial photographs taken in 1937 and 1942 indicate land use was almost entirely agricultural; most of the area was flood-irrigated or nonirrigated cropland. Irrigation ditches, such as the Sand Creek Lateral, extend through much of Sections 35, 26, and 27, and topographic depressions, such as the present-day Basin D, may have been used to retain water for irrigation. Some tracts, however, were apparently

Sand Creek Lateral in Section 35 into a pre-existing irrigation ditch, which emptied into two natural depressions in Section 26 (Basins D and E).

Beginning in 1946, overflow from Basin A was channeled into a natural depression in Section 35 (Basin B) and subsequently into Basins D and E in Section 26. Several sites in Sections 36 and 35 were also used for munitions testing and storage during this time. In 1947, after World War II, portions of the South Plants complex were leased to Colorado Fuel & Iron (CF&I) which produced chlorinated benzenes, chlorine, and caustic, and Julius Hyman & Company, which manufactured a variety of pesticides. The remainder of the South Plants was used by the Army for agent- and nonagent-containing munitions production, demilitarization, and storage. Aqueous wastes from South Plants were discharged to Basin A. Julius Hyman & Company leased property previously leased by CF&I in 1949, and in 1952 Shell purchased the stock of Julius Hyman & Company.

In 1951, the Army raised and extended the Basin A dam, anticipating the need for an increased liquid holding capacity resulting from GB production at the soon to be completed North Plants complex (Section 25). After GB production began in February 1953, process wastes from North Plants were directed to Basin A via a chemical sewer line. In 1953, the unlined basin network was constructed to handle the tremendous volumes of aqueous wastes that were then being generated. Basin C was built in the southeast quarter of Section 26 and began to receive liquid waste directly from South Plants via the Sand Creek Lateral and Basin A overflow, which was also routed to Basin C through the Sand Creek Lateral. Dikes were raised on the western borders of Basins D and E which then intercepted overflow from Basin C.

During the second half of 1956, the Army constructed Basin F, a 92.7 acre evaporation pond lined with catalytically-blown asphalt north of Basin C in Section 26. The chemical sewer system that linked Basin F with the South and North Plants complexes was completed in November 1956, and transfer of Basin A fluids to Basin F via this line began in December.

In April 1957, as Basin F was filling, wind-induced wave action ripped the liner at the shoreline. An undetermined amount of fluid was pumped to Basin C and the liner was repaired. The remaining fluid in Basins A and C was transferred to Basin F, which by this time was receiving all industrial aqueous waste generated at RMA. GB production ceased in 1957, and the Army also closed the chlorine plant in the South Plants; however, Basin F continued to receive runoff from the North Plants collected in the Building 1727 sump and discharged through the chemical sewer. From February through December 1961, the Army installed the deep disposal well system and related facilities as a means to finally dispose of the liquid retained in Basin F. The deep well facility operated intermittently from March 1962 to February 1966 when earth tremors, possibly induced by the injected fluid, forced the Army to shut it down. Approximately 165,000,000 gallons were injected at a depth of 12,045 ft into Precambrian bedrock during the operation of the well.

Discharges of aqueous waste from pesticide manufacturing, mustard/GB demilitarization, and hydrazine blending operations to Basin F continued after use of the deep well system was discontinued. Effluent discharges to Basin F declined as demilitarization operations decreased in 1977, and Shell installed the Denver Effluent Treatment System in the South Plants complex. On March 31, 1978, Shell stopped all Basin F disposal. The Army continued to discharge wastes from various operations to Basin F until December 1981. Fresh water was diverted from the Lower Lakes via the Sand Creek Lateral and stored in Basin C as early as 1953, and at various times until 1975. Between 1959 and 1967 no records indicate storage of liquids in Basin C.

In early 1982, the chemical sewer lines connecting the South and North Plants with Basin F were excavated or plugged, and the crushed piping and surrounding soil were deposited in Basin F. By December 1982, Shell had terminated all manufacturing activities at RMA. Army activities were limited to munitions storage or transfer and sporadic demilitarization of stored stocks. The deep well was plugged and abandoned in the fall of 1985, and the associated buildings and pipelines razed, excavated, and transported off-post.

Other activities were performed in or adjacent to the NCSA aside from aqueous waste disposal. Various sites in Section 36 were used for solid waste or munitions storage, destruction, or disposal; however, most of these sites are in the Central Study Area. The lime settling basins which retained effluent that subsequently flowed to Basin A, were located in the southwest quarter of Section 36. Lime periodically dredged from these basins and similar basins in the South Plants complex was dumped southwest of Basin A. Button bombs and fuzes were deactivated in furnaces in the north-central portion of Section 36 in the later 1960s until 1971.

Two groundwater interception/treatment systems, the NBCS and NWBCS, were installed in the NCSA to prevent contaminants from migrating off-post (Plate NCSA 1.1-1). The NBCS extends for 6,740 ft through Sections 23 and 24. It was constructed in two phases. The Phase I pilot system became operational in June 1978, and expansion to its present configuration was completed in January 1982. The NWBCS is located in Section 22. The NWBCS is about 1,400 ft long and was completed in October 1984.

Portions of Sections 23, 24, 25, and 26 were also cultivated for TX production from 1962 to 1968. TX, an anti-crop agent that is nonhazardous to humans and animals, was produced in nearly 600 acres of wheat fields in these sections. Wastes from these operations, considered nonhazardous, were disposed in Basin F from 1963 to 1965, and in shallow trenches and abandoned wells in Sections 23 and 24 from 1966 to 1969.

1.3.2.1 Site NCSA-1

NCSA-1a Basin A (Former Sites 36-1, 36-14 and portions of Section 36 Nonsource Area). The area in Section 36 known as Basin A (Plate NCSA 1.1-2) was originally constructed in 1942-43 and consisted of three evaporation ponds (Ponds A, B, and C) for mustard and lewisite aqueous industrial waste (ESE, 1987m/RIC 87203R07). The exact locations and configurations of these ponds are unknown. It has been reported that by 1946 the dam on the western edge of Ponds B and C began to leak. An overflow ditch and an auxiliary dam (Pond C extension) were constructed as a safety measure against dam failure.

In late 1951, the dam on the western edge of Basin A was raised and extended in order to accommodate expected liquid waste from the GB project. This increased the capacity of the basin to approximately 350 million gal and the surface area to approximately 123 acres. By May 1952, the additional capacity was exhausted and abnormally high precipitation led to the overflow of Basin A through a ditch at the northern end of the dam. In the fall of 1952, the fixed level spillway was modified and opened, thus lowering the liquid level in Basin A by 2 ft. Ninety-three million gallons were discharged into an overflow ditch that led to Basins B and D (Plate NCSA 1.1-2).

In late 1953, the Army constructed Basin C and built dikes at Basins D and E to fulfill the need for additional aqueous waste disposal resulting from GB plant operations. The GB plant was served by two chemical sewer lines (a 12 inch steel pipe and a 6 inch cast-iron pipe) that emptied into Basin A.

By 1954, the Army had authorized Shell to construct a new chemical sewer line from South Plants (Buildings 514 and 516) to a concrete stilling basin at the southeastern corner of the Section 36 lime settling basins. The stilling basin emptied into an open unlined ditch that led to Basin A. Prior to this time, wastes from Buildings 514 and 516 mixed with wastes from the eastern half of the South Plants area in a 12 inch pipe that emptied into the lime settling basins and then into Basin A. From 1943 until the closing of Basin A, a 30 inch pipe also served the South Plants area and emptied into the lime settling basins. In December 1956, chemical sewer lines 1, which served South Plants, and 5, which served the GB plant, were completed and in service.

In December 1956, the Army began transferring the contents of Basin A to Basin F. Transfer was interrupted when portions of the Basin F protective soil blanket and underlying liner were eroded by heavy wave action; the liquid in Basin F was pumped to Basin C while repairs were effected. By September 1957, drainage of Basin A to Basin F was completed.

By February 1958, a ditch had been excavated from the Basin A transfer line to Basin B. The ditch passed under "D" Street and across Section 35. Aerial photographs indicate the ditch was in use through August 1982. By 1959, a second line, AA, was constructed along the length of the Basin A dam and connected to the sewer at manhole 5-1 (Plate NCSA 1.1-2). This line may have been used in conjunction with the above ditch. In early 1961, ditches were excavated in Basin A to provide an outlet for surface runoff. The main ditch cut through Basin A and Pond C extension dams and joined with the drainage ditch discharging to Basin B. In the mid-1970s, a series of visual reconnaissance sweeps were undertaken to clean up the surface of Basin A. In May 1977, 143 bottles containing lewisite and mustard were discovered. An additional 268 bottles were found at the same unspecified location in July 1977.

Suspected Mustard Plant Disposal Site (Former Site 36-14)

Former Site 36-14 was originally identified as the probable disposal area for contaminated equipment from the mustard plant and several ton containers of Levinstein mustard. Records Evaluation Report No. 107 (Wingfield, 1977/RIC 81266R68) identified the mustard plant disposal site as the "South Pit," reportedly located in the center of Section 36, possibly at NCSA-1e (former Site 36-15). Geophysical surveys, field reconnaissance, and records evaluations performed during the RI definitively identified the mustard plant disposal site in the Central Study Area. Based on Phase I soil data, the western half of former Site 36-14 has been incorporated into Basin A (NCSA-1a), and the eastern half is now part of Central Study Area, Site CSA-1b.

NCSA-1b Lime Settling Basins (Former Sites 36-4, 36-5, 36-10 and portions of Section 36 Nonsource Area

The lime settling basins (former Site 36-4) were originally constructed by the Army in 1942 to dispose of lime that was generated as a by-product of acetylene manufacture, and to ensure that liquid effluent discharged to Basin A was not acidic in nature (ESE, 1987g/RIC 87203R02). From April to November 1943, lime slurry from the Army's acetylene plant was pumped via overhead lines to the Section 36 lime settling basins. After the Army ended lewisite manufacturing in November 1943, acetylene production also ceased, and the Army stopped putting lime slurry into the Section 36 lime settling basins.

Up until 1953 two chemical sewers discharged South Plants aqueous wastes into Section 36. The westernmost of these was 30 inches in diameter and emptied into the lime settling basins which subsequently emptied into Basin A via an open ditch. Sometime between March 1953 and February 1954, Shell constructed a new chemical sewer line which essentially paralleled the easternmost pre-existing line and emptied into a concrete stilling basin at the southeastern corner of the lime settling basins. The concrete stilling basin, in turn, emptied into Basin A through an open ditch. The lime stilling basins continued to receive aqueous wastes through the 30 inch line until construction of Basin F and the chemical sewer lines was completed in November 1956. By January 1957, both the Army and Shell had ceased using Basin A and its associated disposal systems, including the lime settling basins and the chemical sewer lines leading to Basin A via the basins, for disposal of aqueous waste.

From approximately 1950 until 1974, Shell and its predecessor, Julius Hyman Co., produced acetylene, an intermediate compound employed in aldrin production. This operation generated lime as a byproduct, which was deposited in slurry form in the South Plants lime pits. Between 1955 and 1962, Shell periodically hauled lime waste from the South Plants lime pits to the lime settling basins or an area near these basins. In 1962, Shell deposited lime excavated from the South Plants lime pits into the lime settling basins, and by 1964, a lime sludge and lime slurry transfer system was approved, thus eliminating the need for dump trucks for the removal of lime.

From 1964 to 1974, Shell pumped lime slurry from the acetylene plant through the South Plants lime pits to the lime settling basins. Sometime during the 1974-1975 period, the Army bulldozed in the banks of the lime settling basins and leveled them off with the existing ground surface.

A suspected mercury spill area immediately south of the lime settling basins, Site 36-5, was originally designated on the basis of the Records Evaluation Report No. 107 (Wingfield, 1977/RIC 81266R68). The Wingfield report, however, incorrectly identified the location of this spill. It actually took place at the lewisite reactor Building 514 in the South Plants Complex (ESE, 1988d/RIC 88063R01). Phase I RI soil data confirmed that mercury was not a potential contaminant at Site 36-5; however, the potential contaminants that were detected in this area are consistent with those found at former Site 36-4 immediately to the north. Thus, former Site 36-5 has been incorporated into the lime settling basins area.

Former Site 36-10

A disposal pit, former Site 36-10, was originally identified on a 1962 aerial photograph as an area of concentric ground scars northwest of the Section 36 lime settling basins (former Site 36-4) (ESE, 1988b/RIC 88033R02). Although the origin or nature of Site 36-10 is unknown, the scars are thought to be related to activities at the adjacent lime settling basins.

Between 1955 and 1962, Shell periodically hauled lime waste from the South Plants lime pits (former Site 1-5) to an area in the vicinity of the lime settling basins. This operation supposedly resulted in a mound of lime that was most likely pushed into the westernmost lime settling basin. The ground scars at former Site 36-10 are thought to have occurred as a result of the filling in of the westernmost Section 36 lime settling basin with the lime. A dirt road leading into former Site 36-10 appears to have been used by Shell's dump trucks for the transfer of lime to this area. Former Site 36-10 has been incorporated into the lime settling basins area (NCSA-1b).

NCSA-1c Basin A to Basin B Drainage Ditches, (Former Site 36-8N)

Basin A overflow was directed northward and eventually westward into Basin B (NCSA-5a) by way of a fixed-level spillway and ditch constructed in 1946 at the northern end of the Basin A earthen dam. This ditch, designated as Sites 36-8N and 35-4 (in Section 35) by the RMACCPMT, emptied at the northeast corner of Basin B. The spillway was modified in 1952 to accommodate the anticipated higher volume of flow resulting from operations at the North Plants. Site NCSA-1c served as the only outlet for Basin A overflow until use of the basin was discontinued. Review of aerial photographs indicates the segment of this ditch in Section 36 was backfilled in 1964; the continuation in Section 35 (NCSA-5b, Site 35-4) is still intact.

A second ditch leads from a breach in the Basin A earthen dam into Section 35 and empties into Basin B. This ditch was dug in 1957 to channel storm runoff collecting in Basin A to Basin B, after all impounded wastes in Basin A had been transferred to Basin F. A subsidiary ditch was added in the Basin A Neck area to accommodate potential overflows in the main ditch. The segments of this ditch in Section 36 were investigated as part of Basin A during the RI and were not designated as a separate site. The ditch extension in Section 35, which empties into the southeastern corner of Basin B, was designated by the RMACCPMT as Site 35-4. These ditches are still intact and continue to seasonally transport runoff from Basin A to Basin B.

The Basin A overflow ditch, former Site 36-8N, and former Site 35-4, are hereafter referred to as the northern Basin A to Basin B Drainage Ditch, Site NCSA-1c, and Site NCSA-5b, respectively. The Basin A runoff ditches, Site 35-4, constructed later, will be discussed as the southern Basin A to Basin B drainage ditches, NCSA-5b.

NCSA-1d Liquid Storage Pool (Former Site 36-11)
From at least 1955 to 1962, the liquid storage pool is thought to have received all surface drainage from the northern part of the South Plants area (ESE, 1987e/RIC 87133R01). Before 1975, surface drainage from the northern part of the South Plants area flowed through a storm drainage system northward under Seventh Avenue and then into the lime settling basins and Basin A. A portion of this storm drainage ditch (NCSA-1f) ran along the western boundary of NCSA-1b and into the liquid storage pool. By 1955, the discharge point of the storm drainage ditch into the lime settling basins was abandoned; in subsequent years, storm runoff was apparently discharged solely into the liquid storage pool. By August 1962, the outlet of the

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storm drainage ditch at the liquid storage pool had been backfilled, and this site no longer received storm runoff from the northern part of the South Plants area. By 1975 construction was completed on the surface drainage canal, which extended the South Plants storm runoff ditch past the liquid storage pool through Sections 36 and 35 and into Section 34.

NCSA-1e Burn Site (Former Site 36-15)

The burning site, NCSA-1e (former Site 36-15), is located in the center of Section 36 near the eastern shore of basin A. Previous documents have identified this area as the "South Pit," where contaminated equipment from the mustard plant and ton containers of Levinstein mustard were purportedly buried (Wingfield, 1977/RIC 81266R68). The RMACCPMT, however, identified Site 36-15 as a burn site where miscellaneous South Plants trash was burned in shallow trenches.

Geophysical surveys, field reconnaissance, and RMA records evaluations performed during the RI have located the mustard plant disposal site in anomaly H of RMACCPMT Site 36-17N, which is southeast of NCSA-1e (former Site 36-15) in the CSA (ESE, 1988a/RIC 88013R05). Furthermore, Phase I and II soil analyses did not detect mustard at NCSA-1e, although one detection of a possible mustard breakdown product was recorded.

Phase I and II data and field observations support the contention that this area was used as a burn site. Boring logs note the presence of a blackened, debris-filled zone 3 to 6 ft below ground surface. It is speculated that trash and solid waste from South Plants were burned here from the early 1940s until 1947, when liquid impounded in Basin A covered the site.

NCSA-1f South Plants Drainage Ditches (Former Sites 36-8S, 36-21)

Two ditches comprise this site: the western South Plants drainage ditch (former Site 36-8S), which transports storm runoff into Section 34, and the eastern South Plants ditch (former Site 36-21), which empties into a small depression south of Basin A.

Before construction of the western South Plants drainage ditch, South Plants surface drainage went through a storm culvert under Seventh Avenue, and then turned eastward and emptied into the southwestern corner of the westernmost basin of the lime settling basins. The outlet of this ditch into the lime settling basins was closed off in 1955, and the ditch was extended to the liquid storage pool (NCSA-1d). Subsequent ground disturbances northwest of the lime settling basins obliterated the ditch south of the liquid storage pool and consequently South Plants storm runoff again entered the lime settling basins.

In 1975, in response to Cease and Desist Orders against Shell and/or the Army, the present-day western South Plants drainage ditch was constructed. The pre-existing storm runoff ditch was enlarged and extended northward and then northwestward through Sections 36 and 35, emptying at the northeast corner of Section 34 to provide a drainage bypass for surface water runoff, thereby preventing rainwater from entering Basin A. The extension of this ditch in Section 35 is referred to as the surface drainage canal (Site NCSA-5d). Standing and flowing water have been observed seasonally in this ditch, and surface water samples were collected during the RI at a gage at the opening of the culvert under December 7th Avenue.

The eastern South Plants drainage ditch (former Site 36-21) is first visible in a 1948 aerial photograph, although the exact construction date is unknown (ESE, 1987c/RIC 87133R03). The ditch appeared to originate approximately 367 ft north of December 7th Avenue and 92 ft west of a parking lot in the south-central portion of Section 36 and extended approximately 400 ft north, emptying into what appeared to be a depression. The ditch was visibly longer in a 1967 aerial photograph and a pool of liquid was visible northeast of where the ditch ended. By 1972, the pool appeared to be dry, although the ditch was still clearly visible. In 1974, two pools of liquid were visible at the northeastern end of the ditch. A metal culvert, which ran north under Seventh Avenue, discharged into the southern end of the ditch. By 1976, the ditch was connected to a surface drainage system that was located east of Building 728 in the South Plants.

During 1979 and 1980, Shell sampled storm runoff water samples from the eastern South Plants drainage ditch. Benzene, methylene chloride, trimethyl phosphate, and chloroform were detected. In 1983, the Army sampled water from the culvert that discharged into the drainage ditch and found trace concentrations of aldrin, isodrin, chloroform, and higher concentrations of dieldrin and endrin.

1.3.2.2 Site NCSA-2

NCSA-2a Basin C (Former Sites 26-3, 26-UNC)

The Army constructed Basin C in the summer of 1953 as part of an emergency project to provide additional waste disposal capacity on the arsenal for GB production. Basin C was completed in 1953 when a 7 ft high riprapped earthen dike was raised along the northern and western perimeters of a natural depression in the southern half of Section 26 (ESE, 1987s/RIC 87343R03). Concrete weirs and unlined ditches were also installed to connect Basins C, D, and E. Basin A and B overflow was directed to Basin C by closing the culvert beneath the Sand Creek Lateral at the Basin B outlet and allowing the fluid to flow into the Sand Creek Lateral and then into Basin C via a ditch installed at Headgate No. 41. All waste fluid entering Basin C was derived from two sources: 1) overflow from Basins A and B; and 2) surface drainage ditches from the South Plants that led into the Sand Creek Lateral. By 1953, Shell had ceased operation of the chlorine plant in the South Plants area, thereby removing a significant portion of the aqueous waste flowing through the Sand Creek Lateral.

By December 1956, construction of Basin F was completed, and all waste fluid from Basin A and RMA was pumped into Basin F. In April 1957, an indeterminate amount of Basin F effluent was partially drained and retained in Basin C for 30 days due to a rip in the Basin F liner. When liner repair was completed, all liquid remaining in Basin C was transferred back to Basin F.

On a number of occasions from the late 1950s to the mid-1970s, water from the Lower Lakes in Section 2 was diverted to Basin C via the Sand Creek lateral. Some of this water was used to irrigate TX wheat fields in

Sections 23 and 24. Fresh water was stored in Basin C in 1957, 1958, in 1967, and from 1969 to 1974. Basin C was dry as of June 1, 1975 (Shell, 1988, unpublished). According to Shell, after June 29, 1967, water from Basin C was not used for TX production.

NCSA-2b Basin D (Former Site 26-4)

Prior to 1946, Basin D, a pre-existing natural depression, received waste from the chlorine plant and white phosphorous cup filling operations in the South Plants area diverted from the Sand Creek Lateral (ESE, 1987o/RIC 87293R02). In 1946, the Army built a ditch to carry overflow from Basin A to Basin B which subsequently would overflow through a culvert under the Sand Creek Lateral and into a preexisting drainage ditch which lead to Basin D. By 1948 a permanent dike had been constructed at the western side of the basin.

In 1953, the permanent earthen dike on the western perimeter of Basin D was improved and a concrete overflow weir and riprap spillway connecting Basin D to Basin E were built. All waste traveling down the Sand Creek Lateral from South Plants or overflowing from Basin A now passed through Headgate No. 41 into Basin C. Overflow from Basin C passed through a concrete overflow structure and outlet ditch to Basin D and then to Basin E.

Between November 1953 and December 1956, all aqueous wastes entering Basin D were Basin C overflows originating from Basin A and the Sand Creek Lateral contributed by South Plants manufacturing operations and the GB plant. In addition Army effluent from the white phosphorous cup filling and M-74 incendiary operations in South Plants was discharged via the surface drainage system to the Sand Creek Lateral, which may have conveyed the waste to Basins C, D, and E in Section 26.

After Basin F was completed in 1957, aqueous waste discharge to Basin D ceased. Subsequent fluid accumulations consisted solely of storm runoff and freshwater overflow from Basin C.

NCSA-2c Basin E (Former Site 26-5)
Prior to 1946, the Basin E area possibly received Basin D overflow consisting of Army waste from chlorine production and white phosphorous cup filling operations in the South Plants area (ESE, 1987j/RIC 87203R04). In 1946, the Army built a ditch to carry overflow from Basin A to Basin B which subsequently would overflow through a culvert under the Sand Creek Lateral and into a pre-existing drainage ditch to Basin D and unimproved Basin E.

Basin E was completed in 1953, when permanent earthen dikes were constructed on the western perimeter and a concrete overflow weir and riprap spillway connecting Basin D to Basin E were built. All waste traveling up the Sand Creek Lateral from South Plants or overflowing from Basin A now passed through Headgate No. 41 and into Basin C. Overflow from Basin C passed through a concrete overflow structure and outlet ditch to Basin D, and then to Basin E in the same manner.

Between November 1953 and December 1956, all aqueous wastes entering Basin E were Basin C overflows originating from Basin A and the Sand Creek Lateral contributed by South Plants manufacturing operations and the GB plant. In addition Army effluent from the white phosphorous cup filling and M-74 incendiary operations in South Plants was discharged via the surface drainage system to the Sand Creek Lateral, which may have conveyed the waste to Basins C, D, and E on Section 26.

After Basin F was completed in 1957, aqueous waste discharge to Basin E ceased. Subsequent fluid accumulations consisted solely of storm runoff and freshwater overflow from Basin D.

NCSA-2d Basin B to C to D to E Drainage Ditches (Former Site 26-7)
The ditch extending from the Basin B northwest to Basin D was originally designated by the RMACCPMT as Sites 35-4 and 26-7. Site 26-7 was the short segment of the ditch in Section 26. This ditch, which runs under the Sand Creek Lateral, predates RMA activities and at one time extended into the natural depression that became Basin D. From 1943 to 1954 this ditch carried Basin B overflow to Basin D. After Basin C was completed in 1953,

this ditch was closed off at the culvert beneath the Sand Creek Lateral. Basin C overflow, however, was directed to Basin D through the northernmost section of this ditch. When Basin C was constructed and permanent dikes raised at Basins D and E, a second ditch connecting Basins C and D was dug and the pre-existing ditches interconnecting the three basins were enlarged and lined with rubble. These ditches are still intact.

1.3.2.3 NCSA-3 Basin F (Former Site 26-6)

Basin F, a 92.7 acre disposal pond equipped with a catalytically blown asphalt liner and 12 inch protective earthen blanket was built by the Army between July and December 1956 (ESE, 19881/RIC 88173R02).

Basin F was built on the site of a large natural depression with no documented previous history of disposal use. Eight and 10 inch gravity flow, sealed joint, vitrified clay sewer laterals linked Basin F to the terminal points of the chemical sewer lines from the chlorine plant, the South Plants manufacturing area, and the GB plant. Basin F began receiving flows from the Building 1727 sump in the GB plant in October 1956. By December 1956, final work on the dikes and connecting sewer laterals was complete, and all aqueous waste was discharged to Basin F.

Basin F was used continuously between December 1956 and December 1981 for the solar evaporation of aqueous wastes. After December 1956, no other evaporative basins at RMA were employed for this purpose, except in 1957, when Basins A and C were used on a temporary basis while damage to the Basin F liner and its protective soil covering were repaired. With the exception of GB agent demilitarization wastes, spray dried to packaged salts (after 1973), and those Shell effluent streams either diverted to other disposal facilities, withdrawn before discharge, or incinerated through the Denver Effluent Treatment System (after 1977), most aqueous wastes generated between December 1956 and March 1978 by Army and Shell chemical operations were deposited in Basin F. Following the termination in March 1978 of all Shell discharges to the chemical sewers, the Army continued to discharge contaminated liquid wastes to Basin F as follows: until June 1980, from phosgene transfer, laboratory, and laundry operations; and, intermittently until December 1981, from hydrazine blending activities.

Between December 1956 and December 1981, in addition to rainfall and aqueous waste, Basin F received effluent flows from a variety of other sources. Chemical sewers transported surface water runoff, particularly from the South Plants, which entered the basin throughout much of this period. After repair of the Basin F liner in 1957, aqueous wastes in Basin A were drained to Basin F through a siphon-pipeline system connected to the GB chemical sewer lateral at Manhole 5-1. Thereafter, until the summer of 1960, the Army drained surface water accumulations in Basin A to Basin F by means of a ditch and sump, also connected to the GB chemical sewer lateral at Manhole 5-1. At various times, groundwater seeping into the basements of Buildings 422 and 742A was discharged through the chemical sewer to Basin F. In May 1975, the Army began pumping contaminated water from the North Bog to Basin F on an intermittent basis. Although the introduction in August 1975 of spray aeration reduced the quantities transferred, the pumping continued at least until the end of the year.

A list of the hazardous chemicals known to have been present in discharges of liquid waste to Basin F over time from Army and Shell chemical operations is presented in Table NCSA 1.3-1.

In the summer of 1964, the Army built an earthen-filled dike across the southeast corner of Basin F, creating the 1,000,000 gallon surge basin, F-1 (also known as "Little Basin F"). Upon completion, liquid waste discharged from the chemical sewer bypassed Basin F and flowed directly to the deep well pretreatment facility instead of mixing, as previously, with effluent already in the basin.

Following the termination on December 31, 1981, of all waste discharges to the chemical sewer, the Army implemented a series of measures designed to accelerate the evaporation of remaining liquids in Basin F and to prevent sewer transported flows of infiltrating surface and groundwater and surface runoff from further augmenting the volumes already contained in the basin. Specifically, the Army: 1) removed the chemical sewer trunkline and lateral connections to Basin F from South Plants; 2) plugged the sewer lateral from the GB plant; 3) constructed a pipe trickler system in the basin to enhance natural solar evaporation; 4) installed a dike in the basin separating the wet from the dry areas; and 5) built a north-south surface runoff interceptor ditch along the eastern basin perimeter. In addition, special diking and a new 30 mil PVC liner were installed in a designated storage area in the southeast corner of the basin, providing for environmentally safe disposal of the excavated sewer line and surrounding contaminated soil. As of July 14, 1982, the means for conveyance of further liquid discharges into Basin F had been removed.

The Army Corps of Engineers Waterways Experiment Station (WES) investigated contaminant distributions in Basin F overburden and soils underlying the liner in 1982 (Meyers and Thompson, 1982/RIC 82350R01). during this investigation, the WES noted damage to the liner at three locations, including areas in the southeast and southwest corners of the basin, and along the western edge.

An Interim Response Action for Basin F was proposed in the Technical Program Plan (TPP) for RMA and agreed upon by the United States, the State of Colorado, and Shell in a joint motion filed on June 5, 1987. This was initiated in 1987 with the construction of three tanks in the northeast quarter of Section 26 to contain the impounded fluids. Pumping of the fluids from the basin to the storage tanks was begun in spring 1988. Following liquid transfer, the remaining sludge, liner material, and grossly contaminated underlying soil were excavated and solidified and placed in a temporary waste pile. The Basin F area was subsequently regraded and it and the waste pile were covered with a low permeability clay cap. The entire area has also been covered with topsoil. The Basin F IRA was completed in spring 1989. It should be noted here that the IRA is not considered a final remediation plan. Final disposition of the Basin F area and fluids will be determined after completion of the feasibility study (FS).

1.3.2.4 NCSA-4

NCSA-4a The Deep Disposal Well Area (Former Site 26-1)

A deep disposal well was designed for final disposal of waste fluid stored in Basin F. The well was drilled to a depth of 12,045 ft and used from

March 1962 to February 1966. Surface facilities supporting the deep well injection system were located immediately west of the well and adjacent to Basin F. These included a pump house, treatment plant building, clarifier, several sumps, and a clear-water storage tank. These facilities had the capacity to pressure inject treated effluent into fissures in Precambrian bedrock at rates up to 400 gpm. The deep disposal well area also included chemical sewers used to transport wastes from Basin F to the deep well surface facilities and back to Basin F, as well as numerous other pipelines at the well surface facility.

Between March 1962 and September 1963, approximately 103,600,000 gallons of treated effluent waste were injected into the deep disposal well at rates of 100 to 300 gpm. In September 1963, operations were suspended for an indefinite period due to high costs, frequent mechanical breakdowns, and a surplus storage capacity in Basin F. Operations resumed in September 1964, following a number of modifications designed to improve operating efficiency and lower pre-treatment costs. Between September 1964 and February 1966, approximately 60,960,000 gallons of treated aqueous waste were disposed in the deep well. Injection operations were suspended again in February 1966 because of adverse publicity arising from an apparent correlation between disposal by this method and an increased frequency and intensity of earth tremors in the Denver area during 1965 and early 1966. Deep well operations never resumed after February 1966. From 1962 to 1966 approximately 165,000,000 gallons of contaminated fluid were disposed at this facility (ESE, 1988h/RIC 8[illegible]03R02).

Between 1966 and early 1969, a number of governmental agencies utilized the deep disposal well in support of ongoing research. Strong causal evidence, linking the operations of the deep well to seismic activity in the Denver area (Evans, 1970; Scopet, 1970) was developed as a result of this investigation. The U.S. Army Corps of Engineers (COE) also conducted four pump tests at the well to determine the feasibility of a full-scale pumping program, and whether removal of fluids from the well would induce seismic activity in the area. Following minor earth tremors in October 1968, pump testing ceased.

In 1968, the COE performed a series of cleanout operations at the deep well which entailed the following:

- o Scraping scale from inside the 5.5 inch casing and removing debris from the open-hole section of the well between 11,975 and 12,045 ft;
- o Pumping approximately 105,000 gallons of contaminated fluid back to Basin F;
- o Removing approximately 8,361 gallons of contaminated fluid during a swab test; gravity injecting 9,200 gallons of fresh water to replace fluids removed during the swab test; and
- o Analyzing deep well water for contaminants.

In 1975, the Army relocated the 50,000 gallon storage tank, Building 805 (renumbered Building 758), from the deep disposal well area to the hydrazine storage facility. That same year, contamination was detected in samples taken from the 1,500 ft vitrified clay pipeline (Z line) and surrounding soil. The pipeline was eventually excavated and removed in 1985.

From 1978 through 1983, the Army used Building 802, the waste treatment building, as an experimental laboratory to conduct pilot and bench-scale studies. Building 802 was demolished in October 1985 as part of the Surface Facilities Closure Project. Closure of the deep well and surface facilities involved numerous other operations, including:

- o Removing waste liquids from various building sumps to temporary on-site storage tanks;
- o Demolishing all surface buildings and stockpiling all building materials for removal;
- o Transporting waste liquid removed from the storage tanks to a disposal facility in Oklahoma. Excavating and removing all underground pipelines as well as potentially contaminated soil from the 2 ft interval surrounding each line;
- o Transporting all solid waste to a disposal facility in Utah;
- o Removing a downhole instrument package that became lodged in the well in 1969;
- o Temporarily storing and eventually transporting to a disposal facility in Utah approximately 79,800 gal of waste fluid removed from the well; and
- o Plugging the deep well with cement and abandonment mud.

The Deep Well and Surface Facilities Closure Project was completed in October 1985.

NCSA-4b Basin F Exterior (Former Sites 26-UNC, 23-UNC)

The Basin F exterior area includes portions of the northern half of Section 26 and the southwest quarter of Section 23. Review of RMA documents did not indicate any history of disposal or contamination-generating activities in these areas. However, Phase II analyses indicated low levels of organochlorine pesticides present in the surficial soils of these areas, probably resulting from airborne contamination from Basin F (ESE, 1988k/RIC 88173R02A). Between 1961 and 1966, the Army intermittently operated a spray raft to enhance evaporation of Basin F. Although the Army attempted to prevent contamination of shoreline areas around Basin F by restricting operations to times when wind and humidity conditions were within specific parameters, some droplets and possibly the salt particles resulting from the evaporation of the droplets were transported to adjacent portions of Section 26. These areas are included in NCSA-4b.

1.3.2.5 NCSA-5

NCSA-5 Basin B (Former Site 35-3)

Basin B (ESE, 1987k/RIC 87203R05) was formed in 1946 when the northern Basin A to Basin B drainage ditch (NCSA-1c, NCSA-5b) was dug directing Basin A overflow into a swamp-like area in the northeast quarter of Section 35. This depression was drained, in turn, by another ditch (the Basin B to C drainage, NCSA-5b), which led to another depression (Basin D, NCSA-2b) in Section 26. In response to the increased aqueous waste volume resulting from operations at the GB plant (NPSA), the unlined basin system was expanded in 1953. Basins D and E were improved, and Basin C was constructed. Basin B overflow was subsequently redirected into the Sand Creek Lateral, which emptied into Basin C in Section 26. Use of Basin B as the primary receptor of Basin A overflow was discontinued when Basin F (NCSA-3) and the chemical sewers (NCSA-6) were brought on-line in December 1956.

Basin B began to receive surface runoff from Basin A in 1957 when the southern Basin A to Basin B drainage ditches were dug. The main ditch begins near the northeastern shore of Basin A, cuts through the earthen dam, and extends to the southeast corner of Basin B. This ditch is still open and seasonally directs storm runoff into Basin B.

NCSA-5b Basin A to B to C Drainage Ditches (Former Site 35-4)

Site NCSA-5b is comprised of three generations of ditches which were dug to facilitate drainage from Basin A to Basin B and from Basin B to Section 26. The northern Basin A to Basin B drainage ditch (designated as Site 36-8 in Section 36 by the RMACCPMT) was dug in 1946 to handle Basin A overflow. It extended north from the earthen dam at Basin A, curved west, and continued into Section 35, where it emptied into Basin B. The segment of this ditch in Section 35 was designated as part of Site 35-4 by the RMACCPMT. At the time the northern drainage was constructed, Basin B was a natural depression that drained via a northwest trending ditch into another natural depression (which later became Basin D) in Section 26. Basin B, Basin D, and the Basin B to D drainage ditch apparently were part of the irrigation system used by homesteaders prior to the creation of RMA. The RMACCPMT also designated the portion of this Basin B to Basin D drainage ditch in Section 35 as Site 35-4. Approximately 800 ft of this ditch in Section 26 were identified as RMACCPMT Site 26-7. Most of the ditch in Section 26 was later incorporated into Basin C.

After Basin C was constructed in 1953, the Basin B to Basin D overflow ditch was closed. Overflow from Basin B was directed into the Sand Creek Lateral and subsequently into Basin C. Use of the unlined basins to receive overflow from Basin A was discontinued after Basin F was completed. Later that year a runoff ditch was excavated from the earthen dam at Basin A to the northwest, emptying into Basin B. A southern spur was also constructed to accommodate any ditch overflow. The RMACCPMT did not designate the eastern portions of these overflow ditches in Section 36 (contained within Basin A) as a specific site. The western portions of these ditches running through Section 35 into Basin B were designated by the RMACCPMT as part of Site 35-4.

The Basin A overflow ditch (referred to in this report as the northern Basin A to Basin B drainage) was apparently closed and partially filled in Section 36 in 1964. The Basin A runoff ditches (referred to in this report as the southern Basin A to Basin B drainage) continue to direct any runoff in Basin A to Basin B.

The ditch leading from Basin B into Section 26 was re-opened sometime after 1957 and now carries Basin B runoff into Basin C. Segments of these three ditch sets contained in Section 35 have been included in NCSA-5 as Site NCSA-5b. The portions of the northern Basin A to Basin B drainage contained within Section 36 is part of NCSA-1, Site NCSA-1c. The eastern segments of the southern Basin A to Basin B drainage are considered part of Basin A, Site NCSA-1a. That portion of the Basin B to Basin C drainage designated as Site 26-7 by the RMACCPMT is included in NCSA-2 as Site NCSA-2d.

Sand Creek Lateral, NCSA-5c

The Sand Creek Lateral is an irrigation channel dug in 1911 connecting Sand Creek (off-post, southwest of RMA) with First Creek in Section 25. The Sand Creek Lateral also drains the Lower Lakes in Section 2.

From 1942 until 1956 when the chemical sewers became operational the Sand Creek Lateral carried aqueous waste from the chlorine plant, the white phosphorous plant and the M-74 plant, which were all in the western half of the South Plants complex. In addition, since 1942 the lateral has received surface drainage from this area. The aqueous waste and runoff directed to the lateral were carried through Sections 35, 26, and 25 where the lateral emptied into First Creek. This was discontinued in the mid-1940's when the total dissolved solids level in First Creek became too high. Flow in the lateral was diverted in Section 35 into a pre-existing irrigation ditch which lead to two natural depressions (Basins D and E) in Section 26. In 1953, the Sand Creek Lateral was incorporated into the North Plants and eastern half of South Plants aqueous waste disposal system. Overflow from Basin A, which had previously passed through ditches to Basin B and on toward Basin D, was diverted into the Sand Creek Lateral to Basin C. The Sand Creek Lateral continued to serve as a conduit for aqueous waste from

Basin A to Basins C, D, and E in Section 26 until the new contaminated sewer lines to Basin F were brought on-line in December 1956.

NCSA-5d Surface Drainage Canal

The surface drainage canal in Section 35 is a north and westward continuation of RMACCPMT Site 36-8S which was incorporated into site NCSA-1f, the South Plants drainage ditches. The surface drainage canal was constructed in 1975 to facilitate the drainage of surface and storm runoff from the South Plants area.

1.3.2.6 NCSA-6

NCSA-6a South Plants Chemical Sewer (Former Sites 26-9, 35-2, 36-20s)

Site NCSA-6a is the former location of a 9,700 ft long vitrified clay, gravity flow chemical sewer line connecting South Plants with Basin F. A subsidiary line from the North Plants complex (NCSA-6b, former Site 36-20N) joined the South Plants chemical sewer system in the northeast corner of Section 35 (ESE, 1987b/RIC 87133R02).

The chemical sewer was constructed in stages as RMA facilities were built or expanded. The first stage was constructed in 1942 and connected the chlorine plant with what was to be the caustic waste basin (former Site 35-9). Although this line was reportedly never used for caustic waste disposal, the southern portion of this line in 1956 became part of the chemical sewer system directing aqueous waste from the West Plants manufacturing complex in the South Plants to Basin F. Later stages, constructed from 1942 to 1954, carried aqueous waste from the eastern half of the South Plants Complex to the lime settling basins in Section 36 or directly to Basin A. These lines were plugged and abandoned in place when the Army completed the South Plants Chemical Sewer in 1956.

In 1982, most of the chemical sewer system was removed due to reported leakage. The northern lateral of the sewer line in Section 36, which leads to the North Plants, was not removed according to field observations. Crushed sections of the excavated sewer line and the excavated contaminated soil were placed in a specially constructed storage area situated in the southeast corner of Basin F. All trenches created during the sewer removal operation were backfilled with uncontaminated soil taken from a borrow pit east of "D" Street between Basin C and the GB plant.

The South Plants chemical sewer system contained a number of sections of underground gravity flow, vitrified clay pipe laterals built and used at different times for the transport of contaminated aqueous wastes from the East Plants manufacturing complex in South Plants to either Basin A or to Basin F (ESE, 1987b/RIC 87133R02). In 1956, the Army built two 8 inch underground gravity flow vitrified clay chemical sewer laterals (Lines 1 and 2) to redirect South Plants aqueous waste from Basin A to Basin F. Previously existing 30 inch and 12 inch sewer lines which were constructed in 1942 and directed wastes to the lime settling basins or directly to Basin A, were left in place. Before November 1956, overflows from the lime settling basins passed directly to Basin A by way of open ditches. Following completion of these new sewer laterals and the trunk line to Basin F, the 30 inch line was plugged at manhole 1-12 in the South Plants Study Area, and the two 12-inch lines were blocked at manholes 2-1 and 2-2 in Section 36 (Plate NCSA 1.1-2), thereby preventing further discharges to Basin A.

After 1957, concerns over possible leakage from the chemical sewer laterals and trunkline to Basin F were expressed on a number of occasions. In 1960, a U.S. Army Environmental Health Laboratory industrial waste study report hypothesized leakage in the sewer lateral and trunkline on the basis of discrepancies in flow measurements.

In 1975, the State of Colorado recommended investigating the chemical sewer laterals and trunkline to Basin F for indications of leakage. In 1976, the Army responded by installing measuring instruments along the South Plants chemical sewer trunkline. Exploratory probes were drilled in Section 35, and near where the North Plants chemical sewer lateral (Line 1) crossed under "D" Street. These investigations revealed evidence of leakage (ESE, 1987b/RIC 87133R02).

The Army moved to terminate use of Basin F following cessation of Shell aqueous waste discharges to Basin F through the chemical sewer (March 1978) and the diversion of most Army aqueous waste disposal to other facilities (June 1980). The Army's preliminary closure plan for Basin F (June 1981) specified removal of the chemical sewer trunkline in Sections 35 and 26 and removal of the sewer laterals in the south part of Section 36 in order to prevent further surface drainage and infiltrating groundwater discharges from the chemical sewer into Basin F.

In 1982, Cornerstone Builders, Inc. finished excavating and removing the chemical line and surrounding contaminated soil to Basin F. All soil within 2 ft of any point of Lines 1 and 2 and the associated manholes was classified as contaminated and removed along with the sewer line and appurtenant structures to a specifically lined and diked disposal area located in the southeast corner of Basin F. At completion, it was estimated that 9 cubic feet of contaminated soil had been removed for every linear foot of excavated sewer line. Trenches created in the course of the excavation were backfilled with uncontaminated soil from a borrow pit located east of "D" Street, between Basin C and the GB plant.

NCSA-6b North Plants Chemical Sewer (Former Sites 25-3, 36-20N)
The North Plants chemical sewer consisted of three major parts: a cast iron collection network, a contaminated waste sump (Building 1727), and two pressurized chemical sewer trunk lines, which extended from the sump in the NPSA to Basin A in Section 36 and to Basin F in Section 26 (Ebasco, 1988h/RIC 88286R08). The North Plants complex was designed and constructed by the Army from 1950 to 1952 for the manufacture of the nerve agent GB; filling of GB munitions; assembly of cluster bombs; and storage of GB, feedstock chemicals, and munitions. In later years, the GB facility was also used for the following:

- Phosgene demilitarization (1965 to 1967);
- Microgravel mine production (1967 to 1968);
- M-34 cluster demilitarization (1973 to 1976);
- Demilitarization of GB stored in underground tanks (1974);

- Demilitarization of GB stored in ton containers (1975 to 1976);
- Honest John demilitarization (1976);
- Pilot test program for demilitarization of Chemical Agent Identification Sets (CAIS) (1977 to 1978);
- Demilitarization of CAIS (1981 to 1982);
- Demilitarization of DDT-contaminated small arms munitions (1983); and,
- Demilitarization of adamsite (1983 to 1984).

The North Plants chemical sewer in Section 36 was joined to the chemical sewer interceptor line in Section 35 at Manhole 1-4 by an 8 inch vitrified clay pipe line and four manholes, 5-1 through 5-4 (Plate NCSA 1.1-2). Manhole 5-4 is located at the discharge end of the 6 inch cast iron pipe from the North Plants. Sometime between 1953 and 1961, a 12 inch steel discharge line was installed to connect the sump (Building 1727) to Manhole 5-4. In 1982, the chemical interceptor line between South Plants and Basin F was removed, including a portion of the line west of Manhole 5-1 and crossing former Site 36-18. A review of available documentation (see: CAR Site 36-18, Possible Trench Disposal Site; ESE, 1988e/RIC 88063R06) suggests that the portion of Line 5 east of Manhole 5-1 and within Section 36 was not excavated.

1.3.2.7 NCSA-7

North Boundary Containment System

The North Boundary Containment System (NBCS) is located just south of the north boundary of RMA in Sections 23 and 24 (Plate NCSA 1.1-1). The NBCS consists of a dewatering system to withdraw contaminated groundwater; a soil-bentonite barrier to separate contaminated and treated groundwater and impede off-post migration; a carbon-adsorption treatment system to remove organic contaminants; and a recharge system to return treated groundwater to the alluvial aquifer.

The NBCS was constructed in two phases during 1978 and 1981. The existing soil-bentonite barrier is 6,740 ft long and approximately 3 ft wide, with a design hydraulic conductivity of 1×10^{-7} cm/sec or less. The completed NBCS incorporated 54 dewatering wells upgradient from the soil-bentonite barrier to intercept groundwater approaching the RMA north boundary. Thirty-eight recharge wells returned treated water to the alluvial aquifer. Thirty-five of the dewatering wells are screened in the alluvial aquifer, and 19 dewatering wells are screened in Denver Formation sandstone units beneath the system. The Denver aquifer dewatering wells have not been used since the fall of 1984.

Extracted groundwater is treated in a carbon-adsorption system and discharged to a sump prior to recharge. The system averages 200 to 300 gpm.

Since 1982 the North Bog (NCSA-7) has been used as recharge basin for effluent from the NBCS. Four of the recharge wells serving the NBCS were shut down and approximately 45 to 50 percent of the NBCS effluent was redirected to the North Bog by hoses above ground. Estimated average flow to the North Bog was 117 gpm (ESE, 1988ss/RIC 88344R02). This practice eventually created an artificial groundwater mound beneath the bog in addition to raising the water level in the bog itself.

In the Summer to Fall 1988 an Interim Response Action (IRA) was performed to improve the recharge capability of the NBCS. This IRA involved the installation of ten east-west trending trenches approximately 45 ft downgradient of the soil-bentonite barrier. The trenches were excavated by first digging a working platform approximately 100 ft by 40 ft and 5 ft deep. Air monitoring using photoionization detectors (PIDs) and organic vapor analyzers (OVAs) was continuously conducted during this activity and no readings were recorded. This soil was thus considered "clean" and piled adjacent to the working platform. A backhoe was then positioned within the working platform and used to dig a trench 100 ft long down to bedrock (approximately 25 ft). Air monitoring was also performed during this phase using PIDs and OVAs. The soil excavated during trenching was piled on the working platform adjacent to the trench. Upon completion the trench was backfilled, first with coarse gravel and then the excavated soil that had been placed on the working platform. The backfilled trench was then covered with a permeable synthetic fabric and the working platform area backfilled to the ground surface with the "clean" soil that had been set aside.

Effluent from the treatment system currently enters the recharge trenches by underground pipelines, and water levels in each trench are monitored by piezometers. The trenches became operational in October 1988 and water levels in the North Bog have since subsided (J. D. Smith, PMO, Personal Communication). At present the North Bog still receives about 20% of the effluent from the treatment system while the recharge trenches receive about 30% (D. Strang, RMA, Personal Communication). More information regarding the installation of the recharge trenches is given in the Implementation Document, MKE 1988b/RIC 89139R01.

NCSA-7 North Bog (Former Site 24-7)

The North Bog is a 2.74 acre (119,400 ft^2) water-filled depression in the northwestern corner of Section 24 (Ebasco, 1988b/RIC 88076R05). The bog was formed in this depression in the early 1900s when farmers installed drainage tiles in nearby fields, routing water toward the depression. During periods of high rainfall, water from First Creek also flowed into this depression. RMA operations have influenced the hydrology of the North Bog. In the 1960s the diversion of water from the Highline Lateral Canal to Basin C caused high groundwater levels north of Basin F as well as in the North Bog area. A 1962 aerial photograph revealed several ditches capable of receiving water that drained into the bog.

Between 1963 and 1965 the North Bog was enlarged, and water from the bog was pumped out and used to irrigate TX (wheat rust) crops in Sections 23 and 24. Later, several unsuccessful attempts were made to dry out the bog, including the construction of canals southwest from the bog.

In early 1974, chemical analyses of surface water samples from the northern end of Ditch D1, which extended off-post from the northeast corner of the North Bog, revealed the presence of diisopropylmethyl phosphonate, dicyclopentadiene, dieldrin, and endrin. Later that year, the north-south culvert of Ditch D1 was sealed and an earthen dike was constructed at the bog in order to stop discharge of surface water off-post. A ditch was also excavated east of the bog to temporarily provide additional storage capacity due to the inflow of surface waters exceeding the pumping capacity of the spray system that led to an area east of Basin F. By October 1975 the ditch had been backfilled.

In 1975, chemical analyses of untreated bog water samples revealed the presence of aldrin, dieldrin, dicyclopentadiene, diisopropylmethyl phosphonate, and endrin. That year, additional actions were taken to stop off-post discharge of surface waters and prevent bog water from flowing over the dike north of the bog. These actions included pumping bog water to Basin F, spraying bog water east of Basin F and south of the North Bog, filling in a ditch that entered the bog, and constructing the groundwater barrier and treatment system.

By June 1975, water pumped from the bog and heavy rains combined to fill Basin F to within 2 ft of the top of the dike. To reduce the amount of bog water pumped into Basin F, an inflowing ditch and stream channel to the bog were infilled, and irrigation sprinklers were installed on the pipeline between Basin F and the bog. In May 1976, the irrigation pipeline was relocated to the eastern side of Section 23, and a dirt access road was constructed parallel to the field sprinkler lines in order to improve the effectiveness of the pumping operations. Spraying of bog water continued intermittently until 1978.

From October through November 1976, RMA operated a 10,000 gal/hr water treatment plant in Section 23. The plant was used to evaluate a powdered carbon treatment process and its capability to remove organic contaminants from bog water. Processed bog water was pumped to Section 24 just east of the treatment plant and sprayed through an irrigation system. Tests indicated that the treatment system was able to reduce concentrations of organosulfur compounds, diisopropylmethyl phosphonate, dicyclopentadiene, and organochlorine pesticides to below detectable levels.

In 1977, the Army conducted a series of recharge system tests using water from the North Bog. Bog water was pumped through a 6 inch pipeline to test sites in Section 23. There was no indication that bog water was treated before it was recharged.

In March 1982, several recharge wells were connected to the North Bog by hose, as part of a contingency plan to augment the capacity of the NBCS recharge system. By 1983, the North Bog was continuously in use as a natural recharge basin for treated groundwater from NBCS because the capacity of the recharge wells in the boundary system began to drop. At no time was untreated water sent to the bog. As a result of this practice, an artificial groundwater mound was created under the bog and water levels in the bog itself rose. In fall 1988, ten recharge trenches were installed upgradient of the North Bog and these began receiving approximately 30% of the NBCS effluent (D. Strang, RMA, Personal Communication). Water levels in the North Bog have since decreased (J. D. Smith, PMO, Personal communication), although at present the North Bog continues to receive about 20% of the NBCS effluent.

Northwest Boundary Containment System

The Northwest Boundary Containment System is located along the northwest boundary of RMA in the southeast quarter of Section 22 (Plate NCSA 1.1-1). Construction of the NWBCS began in March 1983, and the system became operational in 1984. The purpose of this system was to intercept and remove dibromochloropropane (DBCP) and other organic compounds from a plume of potentially contaminated groundwater originating within or to the southeast of Section 26. The system consists of a line of 15 upgradient dewatering wells, a carbon-adsorption treatment facility, and a line of 21 downgradient recharge wells.

Along the northeast part of the system, between the line of dewatering and recharge wells, is a soil-bentonite barrier approximately 900 ft long, 3 ft wide, and up to 30 ft deep. The soil-bentonite barrier was constructed of a bentonite and native soil mix to provide a hydraulic conductivity of 1×10^{-7} cm/sec. The barrier is anchored 2 ft into the Denver Formation and truncates a saturated alluvial thickness of approximately 10 ft. Southwest of the soil-bentonite barrier, the bedrock surface decreases in elevation, causing the thickness of saturated alluvium to increase to approximately 30 ft. The system was designed to withdraw, treat, and inject about 1,500 gpm. Currently, the system flow is 500 to 700 gpm, and a predominant amount of the recharge is in the southwest part of the system.

1.3.2.8 NCSA-8

NCSA-8a Sanitary Sewers (Former Sites 24-5, 25-2, 26-8, 34-2, 35-1)
The sanitary sewer system (former Sites 34-2 and 35-1) was installed in the railyard and administration areas during the construction of RMA in the 1940s. Because construction of the sewer system was not complete before RMA began operations, the railyard and temporary administration areas (former housing area) were serviced with septic tanks and drainage fields prior to connection with the sewer system. A 1945 history of RMA (CWS, 1945b) indicates that both of these areas were connected to the sanitary sewer system by that time.

Two lift stations are located between the railyard collection system and the tie-in with the interceptor sewer line leading to the sewage treatment plant facility in Section 24 (NCSA-8b, former Site 24-6). Approximately 6,800 ft of steel pipe carries wastewater under pressure between these lift stations and then to a 12 inch gravity line north of the permanent administration building, Building 111. Much of the steel pipe used for this line was previously used, and some was pitted by corrosion (CWS, 1945b). No documentation was located indicating that the pipe was repaired prior to installation. Overflow from the lift station north of the railyard (Building 393) ran into a shallow depression northwest of the station and just east of "B" Street (CWS, 1945b).

The second lift station (Building 392) overflowed to the septic tank and drainage field used previously by the temporary administration area prior to connection with the sewer system (CWS, 1945b). Visual observations indicate that the overflow was disconnected from the septic tank and drainage field and now discharges to a ditch and depression northwest of the lift station.

The sanitary sewer interceptor line (former Sites 35-1 and 26-8) was built by the Army in 1942 to transport sanitary wastewater from the railyard, administration, and South Plants areas to the sewage treatment plant in Section 24. In 1952, the North Plants sanitary system was connected to the interceptor line. The collection system was originally designed to handle 1.4 million gallons per day; however, flows in recent years have only been

20 to 33 thousand gallons per day (USAEHA, 1984/RIC 86213R02; USAEHA, 1985). The interceptor line was in use before the sewage treatment plant began operation in January 1943. During this time, sewage was diverted to a temporary open septic tank approximately 125 ft west of Manhole 40. Effluent from the septic tank was discharged to the surface west of Manhole 40, toward Basin C (WRS, 1942; CWS, 1945b). The septic tank was also used on at least two occasions to divert sewage away from the treatment plant when caustic contamination had entered the sanitary system (CWS, 1945b). No documentation was located regarding the removal of the septic tank.

Only one change was made in the sewer line after its construction. During the early 1950s infiltration of fluid from Basin A reportedly killed bacteria at the sewage treatment plant (RLSA, 1985). To correct and prevent this problem, a portion of the sewer line was rebuilt. Four manholes and 1,172 ft of 18 inch reinforced concrete pipe were used in relocating the sewer line to the west and above the high water level of Basin A (DOACC, 1952).

The sanitary interceptor line reportedly has been contaminated with a variety of potential contaminants, including aldrin, carbon tetrachloride, chloroform, DBCP, dicyclopentadiene, dieldrin, p-chlorophenylmethyl sulfoxide, trichloroethylene, vapona, and p-chlorophenylmethyl sulfone (Ebasco, 1988c/RIC 88126R06; Shell, 1979). Contamination has been linked to two primary sources: the infiltration of groundwater from the Basin A area into the interceptor line, and the possible pollution of the sanitary sewer system by the chemical sewer system in the South Plants manufacturing complex (Adcock, 1978). Several corrective measures have been undertaken to reduce contaminant levels in the sanitary sewer line and the sewage treatment plant, in addition to the line replacement previously mentioned. These measures included jet cleaning of the sanitary sewer lines in the South Plants area, and replacement of lines and service connections in the South Plants area that were suspected as sources of potential DBCP contamination (Knaus, 1978; Knaus 1979). These procedures have reduced levels of contamination in the sanitary sewer interceptor line (Shell, 1979).

NCSA-8b Sewage Treatment Plant (Former Sites 24-6)

The sewage treatment plant (Building 391) (former Site 24-6) was constructed in 1942 for the treatment of domestic sewage (Ebasco, 1988j/RIC 87216R08). The plant was designed on the basis of a 4 hour detention period at a flow rate of 420,000 gal/day from a population of 6,000. Information on the disposal of sludge from the plant was not located, although sludge may have been disposed in trenches adjacent to the plant.

In a 1961 map of the sewage treatment plant, the area appeared as it does today except for the size and location of the sludge lagoon and the presence of additional surface drainage. In 1969, a final settling pond was constructed in the area of the sludge lagoon to hold and disinfect sanitary waste. In April 1979, samples collected from the sewage treatment plant effluent contained DBCP (509 ug/l) and other chemical contaminants generated by Shell operations. Contaminated effluent flowed into an unlined evaporation (settling) pond located adjacent to the sewage plant. In the following months, a carbon filtration unit, a sand and gravel prefiltration unit, and an on-line ozonation system were installed to treat the contaminated effluent. In September 1979, a tertiary treatment system was installed to control DBCP levels found in plant effluent.

In 1981, a carbon source and reactivation study was conducted in addition to an operation and maintenance inspection by the U.S. Environmental Protection Agency (EPA). No wastewater from the hydrazine blending operation or the railroad car cleaning operation was found in the sewage treatment plant discharge. In 1984, a surface water sample from the sewage treatment plant lagoon contained no detectable DBCP, diisomethyl phosphonate, or chlorinated pesticides, and only a trace amount of organosulfurs.

1.3.2.9 Balance of Areas Investigated

Nonsource Areas of Section 22 (Former Site 22-UNC)

Section 22 Nonsource Area was used by the Army as a buffer zone for RMA operations and was an agricultural area (ESE, 1987t/RIC 88013R01). Section 22 was leased for farming and grazing activities from approximately 1943 until 1969. In 1984, the NWBCS was constructed within the southwestern portion of Section 22 in order to monitor and treat migrating groundwater contaminants.

Nonsource Areas of Section 23 (Former Site 23-UNC)

The nonsource areas of Section 23 contain a portion of the NBCS and three sites associated with TX anti-crop agent production and disposal. From 1963 through 1968, six wheat fields covering 286 acres in the eastern half of Section 23 (former Site 23-3) were used to grow TX-treated grain. In 1964, three new fields covering approximately 70 acres were added immediately west of former Site 23-3.

Water for TX irrigation was obtained from at least four different sources, including a potable water pipeline, three process water wells in Section 4, the Highline Canal, and the water storage pond at the sanitary sewage treatment plant, Site NCSA-8b. During one growing season between 1963 and 1965, irrigation water was also pumped to Section 23 through above-ground piping from the North Bog (NCSA-7).

During 1963 and 1964, the Army dumped unknown quantities of TX process waste into two wells in Section 23 at former Sites 23-1 and 23-2. In addition, both wells may contain unknown quantities of TX production equipment. These wells were later filled with dirt and the concrete lining collapsed to form a cap.

In April 1975, the Army began pumping potentially contaminated water from the North Bog (NCSA-7) to Basin F (NCSA-3). This action was undertaken to lower the water level in the bog and prevent off-post discharge of surface water. In August 1975, the Army installed irrigation sprinklers on the pipeline between the bog and Basin F and began spraying bog water into nonsource areas of Section 26 east of Basin F.

In August 1976, a prefabricated 10,000 gallon per hour water treatment plant was placed in the eastern portion of Section 23. By November 1976, the plant was receiving and treating surface water directly from the North Bog. After treatment, the bog water was sprayed to the east in nonsource areas of

Section 24. Treatment and spraying of bog water was discontinued by the end of 1978. Nonsource areas in the southwestern quarter of Section 23 have been included in Site NCSA-4b, Basin F exterior. Surficial soil analyses indicate these areas may have been affected by windborne contamination from Basin F.

Nonsource Areas of Section 24 (Former Site 24-UNC)

Nonsource areas of Section 24 (ESE, 1988n/RIC 88203R03) include former Site 24-1 (suspected TX burial site); former Sites 24-2 and 24-3 (suspected TX disposal wells); and RMACCPMT Site 24-4 (TX production area). The sewage treatment plant (NCSA-8b), the North Bog (NCSA-7), and the eastern half of the NBCS are also located in this section.

The Army conducted Phase I TX field production operations at RMA from 1963 through 1968. Seven wheat fields covering approximately 375 acres were cultivated in Section 24. Water for TX irrigation was obtained from the same sources used to irrigate the Section 23 fields. These sources included a potable water pipeline, three process water wells in Section 4, the Highline Canal, and the water storage pond at the sanitary sewage treatment plant, Site 24-6. During one growing season between 1963 and 1965, irrigation water was also pumped to Section 24 through above-ground piping from the North Bog.

During 1963 and 1964, an unknown quantity of TX process waste material was disposed in two wells located in Section 24 (former Sites 24-2 and 24-3). In addition to the process waste, unknown quantities of TX production equipment may have been disposed in these wells. These wells were later closed by filling them with dirt and collapsing the upper 6 ft of concrete lining to form a cap. Between 1964 and 1969, processed and unprocessed TX waste as well as stockpiled TX spores were disposed in an unknown number of shallow burial trenches at a 30 acre land disposal site in Section 24 (former Site 24-1). Until February 1969, no standard burial method existed, and routine destruction of discarded agent TX was not undertaken. After February 1969, a standard operating procedure was followed, whereby TX waste was rendered inert with ethylene oxide and then buried in a 4 ft deep trench.

During the period 1971 to 1977, Department of Agriculture scientists made numerous inspections of the TX burial plot, former Site 24-1. In November 1977, the Department of Agriculture concluded that the TX production and disposal operations were not a threat to the agricultural communities surrounding RMA.

In late 1976, North Bog water was piped to a treatment building in Section 23. The treated effluent was sprayed into the west-central area of Section 24. Use of this plant was discontinued after three weeks.

Nonsource Areas of Section 25 (Former Site 25-UNC)
The nonsource areas of Section 25 (ESF, 1988f/RIC 88063R09) were originally acquired by the Federal government to serve as a buffer zone for RMA operations. Section 25 was assigned a nonsource status except for the North Plants area and an extension of former Site 36-6 near the southern boundary. Two areas of TX production (former Site 25-1) were included in the nonsource area investigation.

TX-treated grain was grown on plots in Section 25 as well as in Sections 23, 24, and 26 from 1962 through 1968. A summary of TX operations at RMA is presented in the history summaries for these other nonsource areas.

Buildings 1618, 1619, and 1622 are located north of the GB plants area in Section 25. These temporary quonset and wood structures were transported from Section 4 in 1963 and were presumably used by personnel working in the TX program.

In June 1981, the Army's preliminary closure plan for Basin F called for excavation and removal of chemical sewer trunk lines leading to Basin F. Trenches created by the excavation in 1982 were backfilled with uncontaminated soil from a borrow pit in Section 25, which was east of "D" Street between Basin C and the GB plant.

Nonsource Areas of Section 26 (Former Site 26-UNC)

The Disposal Basins C (NCSA-2a), D (NCSA-2b), E (NCSA-2c), and F (NCSA-3) and the deep injection well (NCSA-4a) are the only documented disposal areas in Section 26. In the early 1940's aqueous waste from the chlorine plant and other manufacturing operations in the western half of the South Plants was discharged into the Sand Creek Lateral in Section 35 and flowed north through Section 26 and into First Creek. This practice was discontinued after suspended solids levels in First Creek were found to be too high. Subsequently, Sand Creek Lateral flow was diverted into a pre-existing irrigation ditch in Section 35 which emptied into two natural depressions (Basins D and E) in Section 26. Similarly, from 1946 to 1953, overflow from Basin A, via Basin B, was discharged through the same pre-existing agricultural ditch to Basins D and E, and later into Sand Creek Lateral to Basins C, D, and E from 1953 to 1956.

A chemical sewer line (NCSA-6a) also carried waste from the South Plants complex through Sections 35 and 26 into Basin F. The line was in use continuously from December 1956 until Basin F was closed in 1981. The sewer and some surrounding soil were removed in 1982.

Between 1961 and 1966, the Army intermittently operated a spray raft to enhance the evaporation of Basin F. Although the Army attempted to prevent contamination of shoreline areas around Basin F by restricting operations to times when wind and humidity conditions were within specific parameters, some mist did settle on adjacent portions of Section 26. These areas are included in Site NCSA-4b.

Two other sites were identified in Section 26 by the RMACCPMT (1984/RIC 84034R01): former Site 26-10, a lined basin used to retain irrigation water for TX production fields in Section 23 and the northeastern corner of Section 26; and former Site 26-2, a small wheat field encompassing approximately 38 acres used to produce TX (an anti-crop agent not hazardous to humans or animals). Neither of these areas were considered potential contaminant sites.

In 1975, potentially contaminated water from the North Bog (NCSA-7) was piped to Basin F (NCSA-3). When the basin fluid level became too high, spray irrigation heads were installed on the pipeline and untreated bog water was sprayed to the east. The nonsource areas of Section 26 potentially affected by this operation and windborne contamination have been included in NCSA-4b.

Nonsource Areas of Section 27 (Former Site 27-UNC)

Section 27 Nonsource Area (ESE, 1987u/RIC 88013R02) served as a buffer zone for RMA. Aerial photographs from 1948 clearly delineate two ground scars (former Sites 27-2, 27-3) and a natural depression (Basin G) within Section 27. The ground scars may have been borrow areas used in constructing the dikes on Basins D and E. Basin G was a low lying slough that collected water after rainfall.

Nonsource Area of Section 28 (Former Site 28-UNC)

Section 28 Nonsource Area (ESE, 1987v/RIC 88013R03) was used as a buffer zone for RMA and was leased for cattle grazing from 1959 to 1969. No production or disposal activities are known to have occurred in Section 28 Nonsource Area.

Nonsource Area of Section 34 (Former Site 34-UNC)

In 1942, several building that comprised the barracks areas were located in the southeastern corner of Section 34 Nonsource Area (ESE, 1988o/RIC 88203R04). After RMA was constructed in 1943, the barracks area was used by the Western Chemical Warfare School for dormitories and classrooms. Prior to 1943 and the construction of the permanent sanitary waste system that connected the barracks and warehouses with the sewage treatment plant, an open septic tank and adjacent drain field were used to dispose of sewage. Sewage was directed through two lift stations in Section 34 enroute to the sewage treatment plant.

Site 34-1, which consists of four rectangular ground scars, is in the northeast corner of Section 34 Nonsource Area. No information was obtained from the discovery record regarding the origin of these scars, although they are thought to be borrow pits associated with the construction of the sanitary sewer line.

Since 1975, surface runoff from the South Plants has been directed via the western South Plants drainage ditch and the surface drainage canal (NCSA-1f, NCSA-5d) into an empty field in the northeast corner of Section 34 Nonsource Area, 400 ft south of Eighth Ave.

Nonsource Areas of Section 35 (Former Site 35-UNC)

Section 35 contains 15 areas affected by RMA activities. Of these areas, nine were designated by the RMACCPMT as possible contaminant sites (former Sites 35-1 through 35-9). Except for Sites 35-5, 35-8, 35-9, each of these areas was investigated in a separate contamination assessment report. Three other areas, the Sand Creek Lateral (NCSA-5c), the surface drainage canal (NCSA-5d), and the undesignated trash pits, may have received aqueous or solid wastes. The remaining three areas, the administration area, the Army housing area, and the Air Force facility were not considered to be contaminant sites.

Former Site 35-5: A Ground Disturbance

A ground disturbance appears in aerial photographs taken in the early 1950s. Historical records indicate that the disturbance may have resulted from a Rod and Gun Club planting program or a brush fire (ESE, 1987r/RIC 87313R01).

Former Site 35-6: Possible Munitions Test Area

The possible munitions test area appears in aerial photographs as a circular ring approximately 125 ft in diameter, and is considered to have been the firing range for the 4.2-inch mortar testing program. This site was reportedly used in the late 1940s to test-fire mortars into Section 30, as well as Sections 26 and 29. Flame throwers may also have been test fired and demonstrated in the circular graded area southwest of the site. This site was investigated during the Phase I soil investigation and no contaminants were found. It is now considered a nonsource area of Section 35 (ESE, 1987f/RIC 87204R11).

Former Site 35-7: Firing Range
During World War II, the Army conducted public demonstrations of various munitions (4.2-inch mortars, flame throwers, white phosphorous filled munitions, and smoke filler (FS) bombs from this site. Although former Site 35-7 has been previously designated as the firing range for the 4.2-inch mortar testing program, aerial photographs indicate that former Site 35-6, located at the northern edge of this site, was actually the firing range.

Former Site 35-7 was addressed during the Phase I RI soils investigation and was found to not contain contaminants. It is now considered a nonsource area of Section 35 (ESE, 1988c/RIC 88034R01).

Former Site 35-8: Storage Area and Parking Lot
This former site was used as a parking lot by Army personnel working at the North Plants complex. Based on aerial photographs and the Discovery Record, the Records Evaluation Report No. 107 (Wingfield, 1977/RIC 81266R68), which originally described this site as an area for container storage, was found to be in error.

Former Site 35-9: Caustic Waste Basin
The caustic waste basin was built in late 1942 to contain waste from the chlorine plant; however, the basin was never used.

Undocumented Pits
These pits appear midway between Basin B and the caustic waste basin on a 1951 aerial photograph. No record exists of any disposal activity in this area, and the pits do not appear in subsequent photographs.

Nonsource Areas of Section 36 (Former Site 36-UNC)
From the 1940s through the 1970s, several nonsource areas within that portion of Section 36 in the North Central Study Area were used for activities not related to disposal. These activities included a small popping oven, a munitions deactivation furnace, ground disturbances west of Basin A, and the Section 36 tank farm.

In 1951, an explosives safety survey reported the existence of a small popping oven in the southwestern corner of the fenced Section 36 Nonsource Area. An estimated 1,000 M-1 fuzes (M-19 clusters), many of which were corroded or partially buried, were scattered about the area. Several such popping ovens were designed and built at RMA to explode small munitions.

In 1969, a deactivation furnace was installed in the north-central portion of Section 36 to dispose of sandwich button bombs, as well as to destroy fuzes from the anticipated M-34 GB cluster demilitarization. In 1970, approximately 550 drums of mines, with approximately 6,000 mines per drum, were destroyed. The resulting furnace ash, the explosive chemical residue, and the materials used to clean the salvaged mine drums were destroyed in the former Site 36-17N (CSA-1) burning pits. During the operation, 11,000 gal of freon were recovered and placed in storage.

During fuze demilitarization operations in 1970, 42,205 M-417 fuzes were destroyed in the deactivation furnace, along with 9,420 M-206 fuzes (M-34 white phosphorus grenades) and 9,646 pressure cartridges. Approximately five tons of scrap aluminum and four tons of scrap steel were recovered from the operation and salvaged.

In 1982, Moloney reported the existence of four ground disturbances west of Basin A based on his analysis of a 1975 photograph (Moloney, 1982/RIC 85085R01). These ground disturbances are thought to have occurred as a result of grading performed in conjunction with contouring of Basin A and the construction of the western South Plants drainage ditch (NCSA-1f). Two of these features were later identified as Site 36-13. Historical evidence does not support the identification of these sites as potential locations of contaminated solid waste.

In 1982, Shell shut down its chemical plant facilities, including its tank farm, at RMA. No reported leaks or spills of any substance occurred in the Section 36 tank farm or within the adjoining area of Section 36 Nonsource Area.

Although historical activities in the Section 36 Nonsource Area are not related to disposal or known contamination, windblown soil particles (fugitive dust) from drying Basin A may have been a potential source of surficial contamination in Section 36 Nonsource Area. In 1982, a soil-sealing emulsion (consisting of a 3 percent copolymer emulsion of methacrylates and acrylates) was applied to approximately 75 acres of Basin A to restrict the potential for blowing dust.

Three areas near Basin A were identified by the RMACCPMT as possible contaminant disposal sites: 36-7 (disposal area), 36-13 (trenches), and 36-18 (possible trench disposal sites). These former sites were addressed during the Phase I soils investigation and found to be not contaminated. They are now considered to be nonsource areas of Section 36. Historical summaries of these areas are given below.

Former Site 36-7

Five discrete areas orginally comprised Site 36-7; the two westernmost of these are located in the NCSA north of Basin A, north and south of the Basin A to Basin B drainage ditches (NCSA-1c, former site 36-8N). Ground disturbances noted in the two area north and south of NCSA-1c consisted of apparent surface dump features (ESE, 1988uu/RIC 88063R07). The southern feature was first noted on aerial photos taken in August 1962. The northern feature is visible on aerial photos from October 1975 and was larger than the southern.

The areas were investigated during Phase I of the RI, but were not included in Phase II investigations of former site 36-7, based on Phase I analytical results. The southern feature was apparently used as a temporary equipment dump for surficially decontaminated Army plant equipment. Equipment was stored there for a period of months before being transported to the former site 36-17 North burning pits (ESE, 1988uu/RIC 88063R07). A burning pit may have been located to the southeast, but it is not evident on aerial photos. The northern feature was used starting in 1975 to store Army contaminated equipment. The two surface dump features were used through the late 1970s, apparently in conjunction with the operations the principal part of Site 36-7 to the east in the Central Study Area.

Former Site 36-13

These trenches originated between November 1974 and October 1975, and are characterized by two ground disturbances that are approximately 100 ft apart and appear to be unrelated (ESE, 1987h/RIC 87204R14). The southernmost ground disturbance appears to be a surface ground scar caused by grading activities in the immediate vicinity. The northern ground disturbance appears to be a shallow swale, perhaps created to facilitate drainage of surface water. Former Site 36-13 ground disturbances are not thought to be related to disposal activities on the basis of Phase I analytical and geophysical results and the absence of a documented disposal history.

Former Site 36-18

This site first appears in a 1943 aerial photograph as a rectangular ground scar in the northwest quadrant of Section 36 (ESE, 1988e/RIC 88063R06). Its appearance and proportions resemble the ground scars designated as former Sites 34-1 and 27-2.

Historical documentation does not indicate that former Site 36-18 was used for contaminated waste disposal. Former Site 34-1, which resembles former Site 36-18 and is near the sewer line, is though to have been a borrow pit associated with the sanitary sewer line.

In 1956, chemical sewer lines 1 (former Site 35-2/26-9), which served the South Plants area, and line 5 (former Site 36-20N), which served the GB plant, were constructed to carry Basin A effluent to Basin F. Line 5 crossed former Site 36-18 before joining line 1 west of "D" Street. A manhole for line 5 was also located in former Site 36-18.

In 1981, Stollar and van der Leeden (RIC 81293R05) reported that the water table intersected the chemical sewer line in the Basin A neck area. That year, the Army proposed the deactivation and removal of chemical sewer lines 1 and 5 (NCSA-6a, 6b), since it was estimated that 20,000 gal/day of infiltrated groundwater entered Basin F from the sewer line. Chemical sewer line 1 (NCSA-6a) was excavated in 1982. Line 5 (NCSA-6b) was plugged at its junction with line 1 in Section 36 and left in place..

Former Site 36-22

This site was first indentified in a 1953 aerial photograph as a small pool covering approximatly 1 acre near the western border of Section 36 (ESE, 1988g/RIC 88103R01). No documentation exists describing any use of this site, which appears to be a natural depression, as a disposal area. Phase I soil analyses did not reveal any potential organics contaminants at this former site; therfore it has been redesignated as a nonsource area of Section 36.

1.4 GEOLOGY

The RMA is located in the Denver Basin, an asymmetrical structural depression that formed approximately 67 million years ago during the Laramide Orogeny. The basin is approximately 300 miles long and 200 miles wide, and the eastern flank is gently dipping. The western flank dips steeply, exposing several sedimentary units in outcrop along the Colorado Front Range. The NCSA is located very close to the structural axis of the basin, and regional dip of geologic strata in this area is to the southeast at less than one degree. Surficial material, deposited unconformably atop this erosional surface, consists of several layers of alluvial gravels, sands, clays and eolian material. These materials were deposited during glacial and interglacial events.

The two uppermost geologic units of sediments are being investigated at RMA in connection with the migration of potential contamination from surface sources. These two units include the surficial unconsolidated alluvium (stream and eolian deposits) and the Denver Formation bedrock, which consists largely of ancient deltaic deposits (May, 1982/RIC 82295R01). In the subsections that follow, the geologic character of the NCSA is discussed with respect to the soil zone, alluvium, and the Denver Formation.

Information from numerous sources was researched and analyzed to characterize the surficial and bedrock geology in the NCSA. Lithologic logs from monitoring wells, as well as borings drilled during prior investigations and Tasks 4, 25, 26, 36, 38, 39, and 44 of the RI, were analyzed, interpreted, and incorporated into the subsurface characterization. Local geologic cross-sections were constructed to represent the spatial orientation of strata at depth. Lithologic units were correlated, projected, and mapped throughout the NCSA. This information was correlated with regional studies in neighboring study areas. A regional and depositional perspective on the alluvial and bedrock geology in the NCSA and surrounding area is presented in the Water Remedial Investigation Report (Ebasco, 1989/RIC 89067R03).

1.4.1 Soils

The U.S. Department of Agriculture Soil Conservation Service (SCS) (Sampson & Baber, 1974/RIC 81266R54) has prepared descriptions and maps of the soil associations present at RMA. Shell and MKE recently remapped RMA soils because of observed discrepancies and lack of detail in previous studies. The results of this mapping effort are included in this report. The following summarizes this soil study.

The thickness of the developed soil zone in the NCSA typically extends to a depth of 59 to 70 inches (USDA-SCS, undated; Walsh, 1988). The shallower reported depths are characteristic of areas where disturbed soils, including fill material varying in thickness from 4 to 21 inches, overlie truncated horizons of natural soils of up to 59 inches thick. Disturbed soil horizons may reach greater depths in the NCSA, especially within the unlined basins and adjoining sites. Natural soils in the NCSA are classified in the Bresser-Truckton, Ascalon-Satanta, Weld-Nunn, and Aquic Haplustolls Associations (Walsh, 1988). These soils typically formed in fine to coarse textured alluvium and eolian deposits. Aquic Haplustolls have characteristics affected by seasonal saturation and are poorly drained. Typical soils in the remaining three upland associations range from nearly level to strongly sloping and are well drained. Textures vary in the profile from loamy sands, sandy loams, loams, and clay loams on the surface; to sandy clay loams, loams, clay loams, and clays in subsurface intervals.

Five soils series, three subgroups and two undifferentiated groups (consisting of fill materials, sediments, soils, and structures), comprising 19 mapping units occur in the NCSA (Walsh, 1988). The specific locations of the mapping units are show in Plate NCSA 1.4-1. The major soil series include the Ascalon sandy loams and Weld loams in the northern portion of the study area, and Bresser sandy loams in the central and southern portions. Other less prominent soil series include the Nunn clay loams. Aquic Haplustolls predominate on alluvial terraces, floodplains, and depressions along the First Creek drainage (in the extreme northeast portion of the NCSA), but do not extend significantly beyond this area. Typic Haplustolls occur along minor drainages and depressions and within remnant waterways subject to seasonal rises in the water table. These soils are not extensive in the NCSA. The Petrocalcic Paleustoll unit in Sections 25 and 26 is an extension of the coarse textured material prominent in the North Plants Study Area (NPSA) to the east. This unit also occurs in the central portion of Section 35 on Rattlesnake Hill. Its extent across the NCSA is minor. In addition, portions of the soils in the NCSA are disturbed, and vary in texture from clays to sands.

Physical, hydrologic and chemical properties of key soil series and subgroups that influenced contaminant migration in the NCSA are summarized on Tables NCSA 1.4-1 and 1.4-2. These representative characteristics are summarized from background information provided by the U. S. Department of Agriculture Soil Conservation Service (USDA-SCS, 1967; Sampson & Baber, 1974/RIC 81266R54; USDA-SCS, undated).

Texture, clay content, and drainage capacity tend to vary with depth as well as between soil series. The drainage capacities of the key soil series range from slow to rapid and depend greatly on texture and clay content. Most soils are well drained, including the Typic Haplustolls, which receive runoff but are not saturated for extended periods. The Aquic Haplustolls also receive runoff but may be saturated for extended periods. These soils have properties related to a seasonally high water table. Sandier soils, such as the Ascalon and Bresser, have low clay components, retain less water, and have fairly low bulk densities, thus increasing the infiltration potential of contaminants. Cation exchange capacities tend to be highest in the soils containing argillic, or clay, horizons. Typically, this is most notable below a depth of 12 inches. The Weld, Nunn, and Satanta series and the Aquic and Typic Haplustolls contain clayey soils with high cation exchange capacities. The Aquic Haplustolls lack an argillic horizon and may be mottled below a depth of 12 inches. This map unit also contains many inclusions of Aquolls (wet areas) and Bresser soils with induced water tables.

The pHs of the NCSA soils range from slightly acidic (6.1) to strongly alkaline (9.0), generally with depth. This range of pH in NCSA soils may tend to restrict vertical movement of metals. The Petrocalcic Paleustoll unit may be more alkaline below a depth of 33 inches; however, below this depth sample recovery is difficult due to a highly cemented calcic horizon. The Bresser and Satanta soils also contain solute-restrictive calcareous zones at depths from six to over 57 inches. Some intervals may contain up to 59 percent calcium carbonate equivalent (lime).

The shrink-swell potential of most of these soils is low to moderate (with occasional high zones), which may facilitate vertical permeability, depending on moisture content. Surface water runoff potential ranges from very low in level areas to moderate on steeper slopes. Erosion hazard by wind ranges from moderately severe (Bresser series) to low (Satanta and Nunn series). Soil properties such as texture, organic matter, and clay content, as well as the degree of vegetation cover, will affect soil erosion during high winds.

Most of the soils in the NCSA have low organic carbon contents, varying from less than 0.1 percent to 1.7 percent. The highest values occur in the surface horizons. The sodium absorption ratio values for most soils in the NCSA indicate that the soils are nonsodic, and would not limit plant growth. The exception is in the Aquic Haplustoll soils, where the lack of adequate drainage has resulted in increased salt accumulation potential. Subsequently, the potential for breakdown of soil structure is enhanced under these conditions. The collapse of soil aggregates may cause a subsequent decrease in infiltration and drainage capacity.

The physical, hydrologic, and chemical characteristics of soils in disturbed areas near industrial or other types of structures vary widely. In general, the original surface horizons were either removed and replaced with material of unknown origin, or mixed or buried beneath fill materials. Predominant textures of disturbed soils vary from loamy sands and sandy loams to loams. Finer texture materials may occur at depth. The sandier disturbed soils have properties resembling Bresser soils, while the clay soils resemble Satanta, Weld, and Nunn soils, all of which occur naturally in the NCSA. Most disturbed areas contain less natural organic matter in surface materials due to their undifferentiated makeup. Depth to lime appears shallower than in undisturbed soil series. In the NCSA, the high water line of Basin A was also used to differentiate a disturbed land clayey component from a disturbed land sandy component.

1.4.2 Alluvium

The surficial deposits on the bedrock surface in the NCSA are collectively referred to as the alluvium or alluvial deposits, although both alluvial and eoli materials are present.

All of RMA is covered with unconsolidated, Quaternary alluvial and eolian sediments that may locally reach thicknesses of up to 130 ft in the Western Study Area (Lindvall, 1980a, 1980b). These materials were deposited in response to Front Range glacial and interglacial events, or as a result of recent fluvial and eolian activity.

The seven distinct alluvial units identified at RMA are, from oldest to youngest, the Verdos, Slocum, Louviers, Broadway, Loess/Eolian, Piney Creek, and Post Piney Creek Alluviums (Plate NCSA 1.4-2). The last two are collectively shown as channel fill (Figure NCSA 1.4-1). The generally coarse grained nature of the Verdos, Slocum, Louviers, and Broadway Alluviums indicates these units were deposited in high energy post-glacial and interglacial fluvial regimes that were associated with distal portions of reworked alluvial fan, fluvial terrace, and floodplain deposits. The younger units have grain sizes attributable to eolian or low-gradient stream deposition. The predominant sequences exposed at the ground surface are eolian and may blanket other identified alluvial units.

The Verdos Alluvium is the oldest alluvial unit at RMA and consists of light brown to reddish-brown, poorly sorted, stratified gravel with clay, silt, sand, and ash lenses. The Verdos ranges from 0 to 20 ft thick (Lindvall, 1980). The Verdos Alluvium is fluvially reworked glacial outwash that was unconformably deposited upon the weathered bedrock surface of the Denver Formation. Erosional remnants crop out on isolated topographic bedrock highs in Sections 25, 35, and 36 of the NCSA. The most prominent of these was atop Rattlesnake Hill in Section 35, but was quarried off before RMA was established.

The brown to reddish-brown, well stratified pebbly clay, silty sand, and gravel of the Slocum Alluvium was deposited in two pulses separated by a brief erosional episode. The Older Slocum is well-graded coarse gravel with interlayered sand lenses and has less than 10% silt and clay. It ranges up to 35 ft thick. The Younger Slocum is finer-grained than the Older Slocum, well-graded, and has 20-40% silt and clay. Thickness ranges from 5 to 10 ft. While the two Slocum units are not in contact with one another, they do overly the Denver Formation in large areas of Sections 22, 23, 24, and 26, and along the boundary between Section 34 and Section 35.

The Louviers Alluvium is comprised of coarse grained reddish to yellowish brown arkosic sand and ranges from 5 to 20 ft thick at RMA. Based on regional correlations, the Louviers occurs in contact with the bedrock surface throughout much of Sections 27, 28 and 34 in the NCSA.

The gravelly Broadway Alluvium was deposited following the Louviers Alluvium. It is fluvial in origin, consisting of pink to light brown generally well stratified sand and gravel, and is from 0 to 30 ft thick (Lindvall, 1980). The Broadway Alluvium occurs in Sections 22, 27, 28, and 34 of the NCSA.

Piney Creek and Post-Piney Creek Alluvium form the modern-day flood-plain and comprise the beds of active channels. The Piney Creek Alluvium consists of interbedded sand, silt, and clay. The Post-Piney Creek does not occur in the NCSA.

Fine grained Loess/Eolian deposits blanket virtually all of the NCSA. These deposits unconformably overlie older alluvium and cover large areas of weathered bedrock. Eolian sands were deposited above the Loess throughout most of the NCSA and generally range from 10 to 20 ft thick; however, localized accumulations up to 40 to 50 ft thick occur. The Loess/Eolian sediments were deposited during the late Pleistocene and Holocene Epochs of the Quaternary Period. The Loess is a yellowish to light grayish-brown sandy silt, and the Eolian sand consists of light brown, fine grained sand, sandy silt, and clay.

Alluvial material was deposited on a weathered bedrock surface characterized by paleochannels and bedrock highs formed mainly as a result of Pleistocene erosional events. Several prominent paleochannels occur in the NCSA, the most important of which is the Basin A Neck channel, which begins in Section 36 and extends northwest through Sections 35, 26, and 27 (Plate NCSA 1.4-3). Other prominent bedrock channels in the NCSA include portions of the First Creek paleodrainage system in Sections 23 and 24, a paleochannel trending SE-NW through the southern half of Section 35 into Section 34, and a north-south trending channel in Sections 34, 27, and 22. Numerous less prominent bedrock surface paleochannels occur throughout RMA.

Bedrock highs are reflected by relatively high topographic features in Sections 35 and 25 of the NCSA. The bedrock surface exhibits varying degrees of weathering that may be attributed to subareal exposure and possible secondary alteration along the alluvium-bedrock contact.

Stratigraphic relationships between individual alluvial units are quite complex. Older alluvial units may occupy higher topographic positions than younger units, if younger alluvial sediments were deposited in channels that eroded down through adjacent pre-existing sediments. However, younger units may also occur topographically above older units if erosional events prior to deposition of younger units were not sufficient to erode through pre-existing material. Both situations occur in the alluvium at RMA. Figure NCSA 1.4-2 illustrates the stratigraphic relationships of the various alluvial units and the bedrock surface.

1.4.3 Alluvium-Bedrock Contact

In general, the contact between alluvium and bedrock of the Denver Formation is characterized by a distinct contrast between the coarser sandy and gravelly materials comprising the allu um, and the much finer grained sandstones, siltstones, or claystones of the Denver Formation. Bedrock may be weathered in places at the contact and vary from friable and heavily altered to more lithified, compacted material that is fractured and jointed over a depth interval of less than 5 ft. The average thickness of the weathered bedrock in portions of the NCSA has been estimated at 5.5 ft (ESE, 1988ss/RIC 8834R)2).

The alluvium-bedrock contact is characterized by the paleochannels incised into the bedrock surface and subsequently infilled with generally coarse grained alluvium. In the NCSA, three principal paleochannels have been identified (Plate NCSA 1.4-3). These paleochannels facilitate groundwater migration and largely control the direction and rate of movement of potential contaminants in groundwater in the NCSA.

1.4.4 Denver Formation

As with surficial deposits, the Denver Formation is of concern at RMA because of its potential role as a groundwater conduit. Clear definition of the formation's geologic setting is key to understanding its aquifer characteristics. The depositional history, lithologic characteristics, and stratigraphic relationships of this formation are discussed in greater detail in the Water RI Report (Ebasco, 1989/RIC 89067R08) and the Task 25 Final Report (ESE, 1988tt/RIC 89024R02).

Sediments of the Denver Formation were deposited in a distal piedmont plain environment, are fluvial in origin, and contain volcaniclastic intervals.

Figure NCSA 1.4-3 illustrates the reconstructed Denver Formation stratigraphic column at RMA. The Denver Formation is approximately 200 to 500 ft thick at RMA, and is separated from the underlying Arapahoe Formation by a 30 to 50 ft thick claystone interval called the buffer zone. Each Denver Formation zone represents a period of fluvial sedimentation followed by cessation of channel deposition and subsequent deposition of clays on top of tne sand-rich intervals. Lignitic zones were also deposited above and between the individual Denver Formation zones and serve as marker beds to help distinguish the different sand intervals.

The nomenclature scheme for the Denver Formation stratigraphy (Figure NCSA 1.4-3) utilized in the RI reports is based on the occurrence of a thick, laterally continuous lignitic interval identified as Lignite A (LA). Subsequent lignitic intervals were named LB, LC, and LD down section from this marker. Using LA as the marker bed, Denver Formation zones were assigned a number based on proximity to this unit, with the Denver Formation zone immediately below LA called the number 1 upper (1U) zone, which is, in turn, underlain by the number 1 through 9 zones. Denver Formation zones above LA were assigned a letter designation based on proximity to the lignite marker, with the A zone immediately above LA. A volcaniclastic interval and an associated clay-rich stratigraphically equivalent zone were also identified. Each Denver Formation zone consists of sequences of claystone and siltstone interbedded with discontinuous sandstone units. The individual units within each zone were deposited in a dynamic fluvial system and may represent a wide range of flow regines. Sandstone units corresponding to various incidences of channel development may be locally continuous and interconnected.

Stratigraphic relationships of the Denver Formation units within the NCSA are illustrated in Figure NCSA 1.4-3 and in detailed cross-sections. General regional dip is less than one degree to the southeast. Subcrop data indicate that the Denver Formation units exhibit an apparent north-northeast strike in the north-central portion of RMA, but apparent strike comes more north-south in western portions of RMA (Plate NCSA 1.4-4).

Although Denver Formation zones and the sandstone units contained within them are generally stratigraphically separated by lignitic and claystone zones, in some areas the sands truncate claystones and lignites and occur in contact with underlying Denver Formation zones. Sandstone units in zones 2 and 3 may be in contact with each other or are very close to being in contact near the North Boundary Containment System, while sandstones in zones 1 and 2 may be in contact in isolated wells in Sections 25 and 26. The AS sandstone within Denver zone A truncates LA in the western portion of Section 25, the southeast corner of Section 26, and the northern portion of Section 26, thus increasing the potential for interaction with sandstones in the underlying 1U zone.

Relatively discontinuous, but correlatable lignitic zones occur between Denver Formation zones A, 1U, 1, 2, and 3. These units were deposited in shallow, broad, freshwater swamps and marshes. Variation in lignite thicknesses may be due to shorter depositional time periods or erosion of the units.

LA occurs generally between the A and 1U zones and is the principal lignite marker bed identified at RMA. It is predominantly a lignite with some organic shale, and is 2 to 11 ft thick with an average thickness of 6 ft. LB occurs between zones 1U and 1, and is a lignite with lateral facies variations to lignitic carbonaceous organic shale and black shale. LB is 0.5 to 12.0 ft thick with an average thickness of 5.0 ft. LC occurs between zones 1 and 2 and is predominantly a lignite with lateral facies variation to organic shale. It is 0.8 to 13.0 ft thick with an average thickness of 5.0 ft. LD is a lignite to organic shale horizon that occurs between zones 2 and 3. It is 0.4 to 13 ft thick with an average thickness of 3 ft. Additional lignitic zones have been identified, but data are sparse and their use as stratigraphic markers is limited.

The A zone includes distinct sandstone units described as the AS (channel), AL (lower), AM (middle), and AU (upper) sandstones. The AS channel is stratigraphically equivalent to the AM and AL, with the middle and lower sand zones generally representing lateral crevasse splay or overbank sands of the main channel. The AU occurs above the AS, and the A zone was deposited after the 1U and LA intervals.

Sandstones in the A interval were interlaid with finer silts, clays, and lignitic clays, and are commonly 5 to 10 ft thick but range to a maximum thickness in excess of 40 ft. Fine to medium grained, well sorted sands are associated with a north to south trending channel first identified by May and others (1983/RIC 83299R01), and called the AS sandstone. This channel occurs in Sections 35 and 36 of the NCSA in a north-trending zone approximately 2,500 ft wide and a maximum of 46 ft thick (Figure NCSA 1.4-4). Thinner channels occur in the AL sequence, which exhibits a northeast to southwest trend through Section 35 (Figure NCSA 1.4-4) and northwest to southeast orientation in Section 36.

Alternating sequences of crevasse splay or overbank sands, clays, and silts occur as laterally equivalent facies of the channel sands. These intervals are generally associated with AM and AL units, with AU sediments most likely representative of channel abandonment facies.

Data to assess Denver Formation zone 1U were available principally in central portions of RMA. A channel sandstone 20 to 30 ft thick occurs in Section 35 and shows northwest to southeast channel development. Associated thinner, cleaner, splay or minor channel sandstones occur along channel margins (Figure NCSA 1.4-5).

The sandstones within zone 1U are generally thinner than deeper Denver Formation zones and contain occasional lenses of clay and silt. Descriptions of sandstones within 1U indicate these units are typically fine to medium grained, silty and clayey, fairly to poorly sorted, generally well cemented, and light green gray to olive gray in color. Zone 1U may also contain lenses of claystones and silts, and ranges from thin-bedded to massive. Claystone intervals of this zone are thin-bedded.

Denver Formation Zone 1 was encountered in borings from the north and central portions of RMA. Zone 1 channel sandstones 20 to 30 ft thick, exhibiting general north to south trends, occur in the eastern half of Sections 25 and 36 and along the western margins of these Sections and in the western half of Section 35 (Figure NCSA 1.4-6). These channel sands appear to overlap and are interconnected in Section 26. Zone 1 sandstones have been described as quartz sandstones that are very fine to medium grained, silty, well to poorly sorted, uncemented to well cemented, hard, light gray, light yellow, and yellow brown in color, and occasionally micaceous. 1U sandstones contain oxidized zones or intervals. Sandstones may be massive and better sorted in areas of thick sands and are thinly bedded in areas of thinner sands. Claystones in this zone are hard to brittle, and are dark gray, dark blue gray, or light tan in color.

More data are available to characterize Denver Formation zone 2 RMA-wide than any other Denver Formation unit identified. The composition of zone 2 sandstones is quite varied, but generally consists of fine to medium grained quartz sandstones with clayshale layers. Zone 2 channel sandstones up to 40 ft thick exhibit general northwest to southeast trends through western portions of Sections 26 and 35, as well as in south-central portions of Section 23, eastern Section 26, and eastern portions of Section 35 (Figure NCSA 1.4-7). These sandstone channels appear interconnected in the southern portion of Section 26. Zone 2 units in the north boundary area are less laterally continuous and are characterized by thinner (4 to 20 ft thick) clay-rich splay sands.

Thick channel sandstones of Denver Formation zone 3 exhibit north to south trends through Sections 35 and 26 and occur in northeast to southwest orientation though Sections 23 and 24 (Figure NCSA 1.4-8). Sandstone thicknesses in excess of 20 ft that occur in Section 24 also indicate areas of channel deposition; however, lateral continuity between sandstones is difficult to determine. This zone consists of quartz sandstones that are very fine to medium grained, silty, fairly to poorly sorted, and greenish gray to dark gray.

Zone 3 sandstones in Sections 23 and 24 generally contain interbedded clays that are crevasse splay or overbank in origin, although channel sandstones have been identified in the north-central portion of Section 24. A thick northeast to southwest trending sandstone occurs in the northwest portion of the NCSA and may indicate an area of channel deposition; additional information is necessary to confirm this interpretation.

Denver Formation zone 4 is characterized from data collected mainly in the north-northwest and western portions of RMA. This unit is described as quartzitic sand, generally fine to medium grained, clayey or silty, fairly to poorly sorted, green-gray to dark gray. Sandstone distribution is sheet-like in Sections 22, 23, and 25 (Figure NCSA 1.4-9), and individual units can be greater than 30 ft thick but may contain thick interbedded clays. This distribution pattern and lithologic data indicate zone 4 generally consists of overbank and splay deposits in the NCSA, although channel sandstones have been identified at the North Boundary Containment System (ESE, 1988ss/RIC 88344R02).

Available data indicate that sandstone intervals greater than 10 ft thick may be associated with channel development along the western margin of RMA in Denver Formation zone 5, which is described as generally medium-grained quartz sand. Sandstones in zone 6 are generally less than 10 ft thick. Denver Formation zones 7 and 8 may contain potential channel sandstones greater than 20 ft thick. Data regarding the quartzitic sandstones found in zones 7 to 9 are sparse but indicate sandstones encountered in zone 9 are less than 6 ft thick (EBASCO, 1989/RIC 89067R08).

Channel sandstones have been identified in Denver Formation zones A through 4 and occur in Sections 23, 24, 35, and 36 in the NCSA (Figures NCSA 1.4-4 through NCSA 1.4-9). All of these channels show similar north-south trends and were deposited in the same general location through time. This similar location of sand zones may reflect a recurrent depositional pattern that produced stratigraphically stacked channel sands. However, data defining sand occurrence are most abundant in central portions of RMA, and apparent trends may be a result of data distribution rather than depositional events.

Five cross-sections were selected to help illustrate the subsurface relationships of lithologic units and waste disposal areas in the NCSA. Figure NCSA 1.4-10 presents the locations of the cross-sections.

The cross-sections (Figures NCSA 1.4-11 to NCSA 1.4-15) illustrate the position of the various Denver Formation sands and alluvial materials relative to the major disposal basins within the study area. These and other cross-sections and data derived from Task 25 (ESE, 1988tt/RIC 89024R02) and the Water RI Report (EBASCO, 1989/RIC 89067R08) indicate the wide-spread occurrence of the coarse alluvial materials and shallow sands in the NCSA is of considerable importance. When combined with hydrologic and chemical information, the distribution of these units forms the basis for migration pathway analyses presented in Section 3.0

Cross-section NC1-NC1' is oriented northwest-southeast and extends from the RMA boundary just north of the NWBCS through Basins F, C, and A to the southeast corner of Section 36 in the Central Study Area (CSA) (Figure NCSA 1.4-11). Medium to coarse grained alluvial units are found beneath Basins F and C, locally in contact with sandstones from zone 1.

Cross-section NC2-NC2' (Figure NCSA 1.4-12) is oriented southwest-northeast through the centers of Sections 27 and 23 and extends from the boundary of the NCSA on the southwest to the RMA boundary north of the NBCS on the northeast. Potentially extensive sandstones identified as sandstone units within zones 2, 3, and 4 are present along most of the section, and appear to subcrop to the west. These sandstone units include channel, in addition to overbank and splay, deposits. Thicknesses range from 5 to 40 ft, but are generally on the order of 10 to 20 ft thick.

Cross-section NC3-NC3' (Figure NCSA 1.4-13) crosses laterally through the Basin A Neck paleochannel in the northeast quarter of Section 35 near Basin B. The Basin A Neck paleochannel is incised into fine grained claystones and siltstones of the Denver Formation, but channel walls may include sandstones of the A unit. Underlying the claystones of the 1U, 1, and 2 zones are continuous beds of lignite and sands sometimes coalescing into continuous sand sheets 80 ft thick.

Cross-section NC4-NC4' (Figure NCSA 1.4-14) shows coarse gravels and sands up to 35 ft thick at the base of the alluvial unit overlying bedrock, extending from the southern edge of Section 23 along the eastern margin of Basin F and pinching out near the southeast corner of Section 36. This unit is in contact with sandstones of zone 2 of the Denver Formation in the Basin F area, where the head of a shallow paleochannel system is located (Plate NCSA 1.4-3). The paleochannel is also visible in cross-section NC4-NC4'. This paleochannel system becomes more distinct as it extends to the north and northeast towards the NBCS.

Cross-section NC5-NC5' is drawn approximately along the centerline of the Basin A Neck paleochannel from about Well 35080 to its southeast end (Figure NCSA 1.4-15). The northwest end of the section crosses the eastern flank of the paleochannel. Surficial geology within and along the flanks of the Basin A Neck paleochannel is complex; and a number of apparent cut-and-fill bedding structures are apparent on section NC5-NC5', infilled with materials ranging from coarse gravel-sand mixtures to clays. Bedrock underlying the Basin A Neck paleochannel, while undifferentiated on Figure NCSA 1.4-15, is comprised of claystone, siltstone, sandstone, and lignitic beds. The Basin A Neck has been identified as a principal groundwater flow path from the Basin A area northwest towards Sections, 26, 27, 22, and 23 of the NCSA. Hydrogeologic aspects of the Basin A Neck, and of the NCSA generally, are discussed in the following section of this report, and in the Water RI Report (EBASCO, 1989/ RIC 89067R08), a companion document of the RMA RI.

1.5 HYDROLOGY

The following discussion describes the hydrologic system within the NCSA and provides the background necessary to assess the nature and extent of groundwater flow and contaminant transport through this system. This discussion has been divided into four subsections, each addressing a component of the hydrologic system: surface water, vadose zone, unconfined aquifer (primarily the alluvium), and the confined Denver aquifer. More emphasis is given to the alluvial, unconfined and confined Denver aquifers in this section because groundwater is the dominant component of the hydrologic system in the NCSA and provides the primary transport mechanism for contaminant migration at RMA. The surface water component of the hydrologic system is of lesser significance because the occurrence of surface water is intermittent in the NCSA. The ability of unsaturated material to transmit water from the ground surface to the water table is the focus of the vadose zone discussion.

It should be noted that the geologic materials comprising the vadose zone, unconfined aquifer, and the confined Denver aquifer are in many cases complex assemblages of heterogeneous materials defining a unique three-dimensional framework that has direct bearing and influence on the behavior of water flowing through them. Discussions of the groundwater system must necessarily be somewhat generalized.

1.5.1 Surface Water

There are six major drainage basins within the NCSA, which are identified in Figure NCSA 1.5-1. First Creek is the extreme northwest boundary of the study area and is the only defined channel. Sand Creek Lateral is an abandoned irrigation ditch, which defines the west side of the drainage basin that bears its name and the east side of the Basin F drainage. This channel still receives runoff from South Plants and areas in Sections 35 and 26. The North Bog and the sewage treatment plant in the northeast corner of the NCSA are the other significant surface water features. Figure 1.5-2 illustrates the projected 100-year flood plain area.

The NCSA contains a small portion of the First Creek Basin, as shown in Figure NCSA 1.5-1. There is a gage on First Creek a short distance downstream of its confluence with the sewage treatment plant effluent ditch. Discharge at this gage was 733 acre-ft for the 1987 water year (October-September). Streamflow is intermittent at this point, and First Creek is dry for five months out of the year. The maximum flow at the gage was 257 acre-ft for the month of June 1987 (Ebasco, 1989/RIC 89067R08).

Runoff from the First Creek watershed can be estimated using a simple mass balance approach. The average monthly flow for the 1986 and 1987 water years for the south First Creek gage upstream in Section 5 of the ESA and the north First Creek gage downstream in Section 24 was 82 and 69 acre-ft per month (ac-ft/mo), respectively. The difference is 13 ac-ft/mo. Assuming a typical loss rate of 30 percent of the upstream measurement (RCI, 1982/RIC 82096R01), the volume of flow loss by percolation to the groundwater should be about 25 ac-ft/mo. Thus, the expected flow at the downstream gage at the northern NCSA boundary without considering additional inflow from runoff would be approximately 57 ac-ft/mo. Comparison of this estimate with the actual measured downstream flow (69 ac-ft/mo) indicates runoff contributes approximately 12 ac-ft/mo of the total flow between the two points. When considered over the entire area of the drainage basin (approximately 9 square miles), this estimate corresponds to approximately 0.3 inches per year average annual runoff for the two years.

Sewage treatment plant effluent may be a source of potential contamination within First Creek as determined from water quality samples collected in 1986 and 1987 (ESE, 1988aa/RIC 89024R01). Effluent discharges are small in comparison to First Creek, averaging 1 ac-ft/mo. The values range from 0.5 to 1.8 ac-ft/mo (Ebasco, 1989/RIC 89067R08).

The most significant surface water feature in the First Creek drainage is the North Bog. This three acre pond has been used to supplement recharge of treated water from the NBCS since 1982.

The Basin A drainage is almost entirely contained within the NCSA. The basin normally allows no outflows, but it has been observed to overflow into Basins B and C via the southern Basin A and B drainage ditches after heavy snowmelt. Snowmelt flows produce runoff because evapotranspiration is lowest in the winter months.

Inflow sources for the basin are comprised of local runoff and a limited amount of drainage from the South Plants area introduced by the eastern South Plants drainage ditch (NCSA-1f). The western South Plants drainage ditch (NCSA-1f) is monitored by a gage at the outlet of the drainage pipe extending under December Seventh Avenue from the South Plants Study Area. This ditch was modified in 1975 to direct South Plants runoff away from the lime settling basins (NCSA-1b) and the liquid storage pool (NCSA-1d) and into Section 35. Recent field observations, however, indicate that the ditch may occasionally overflow into the lime settling basins area and subsequently into Basin A. Flows recorded by the gage average 0.8 ac-ft/mo, fluctuating between 0.1 and 2.3 ac-ft/mo. Given that flow in this ditch is constant, drainage from the South Plants area may possibly be connected to a groundwater source.

The estimated average infiltration rate of the soils in Basin A is very low at 0.08 inches/hour (RCI, 1983). Combined with low inflow rates and the lack of vegetation in the ponding area, it is likely that nearly all of the water entering Basin A is lost to evaporation.

A report by MKE concluded that the total average recharge from ponding in the central pool area of Basin A could be estimated at 0.028 cubic feet/second (cfs) (20.3 ac-ft/yr) (MKE, 1988).

The highest water mark for Basin A was estimated to cover 128 acres, based on interpretation of a 1958 aerial photograph. After basin use was discontinued, the impoundments were drained to Basin F, and ditches were constructed connecting remaining pools to further enhance drainage. The surface coverage of the ponded water in the central pools as determined from 1975 aerial photographs was 5.8 acres (Moloney, 1982/RIC 85085R01).

The Basin F drainage actually contains Basins B through F. Basins B, C, D, and E are natural depressions, which were modified by the addition of embankments and other structures to contain overflow from Basin A. The high water levels for Basins B, C, D, and E covered areas of 2.75, 77, 21, and 29 acres, respectively. These basins are normally dry since the source of water is direct precipitation and local runoff from within the limited basin catchment areas, but small ponds or puddles have been observed in these basins after spring snowmelts or relatively high-intensity storm events in spring or early summer and the fall. These ponds generally remain only a few days.

As previously stated, Basin A has been observed to overflow into Basin B, which in turn may overflow into Basin C. Due to the extensive storage available in Basin C, it would take an extreme storm event to overflow into Basin D. This has not been observed during the RI. The U.S. Army Corps of Engineers concluded that the A-E Basin System would not overflow in the event of a 100 year, or Standard Project Storm, rainfall intensity. The 100 year floodplain for RMA is presented in Figure NCSA 1.5-2. The Standard Project Storm flood volume was derived from a cumulative precipitation depth of 7.39 inches in six hours for the First Creek basin (COE, 1983a/RIC 84066R01).

Recharge from Basins B, C, D, and E to the groundwater due to the infiltration of local runoff is low due to the high evapotranspiration rates. A MKE report on groundwater recharge indicates that recharge from the unlined basins would be in the range of 0.25 to 0.88 in/yr (MKE, 1988).

Basin F had a surface area of 93 acres and contained a catalytically-blown asphalt liner to prevent loss of contaminated liquids to the groundwater. Several investigations conducted through 1982 to determine the integrity of the basin lines observed local deterioration and cracking, especially in the east-central portion. However, seepage losses through these areas could not be quantified and were considered to be relatively small.

After use of Basin F for contaminant disposal was discontinued, modifications were performed to divert surface runoff around the basin and to block all inlets so that direct precipitation would be the only source of inflow. The only losses from the basin were through evaporation and possible liner leakage. Since the basin was shallow and the liquid had a high dissolved solids content, evaporation rates differ from those for other water bodies on RMA. The actual evaporation rate for the Basin F fluid is uncertain.

As a result of the Basin F Interim Response Action, all liquid present in the basin in 1988 was removed to specially constructed tanks and a double-lined holding pond. The asphalt liner, overburden, dried sludges and soil, and chemical sewer and enhanced evaporation system piping were placed in a double-lined wastepile. The basin floor has been capped with a foot of compacted clay, and contoured to direct any surface runoff from precipitation to the northeast. Consequently, Basin F as a potential source of seepage or evaporation of contaminants has been effectively eliminated, pending a decision on final remediation methods to be applied to the stored liquid and solids and remaining contaminated soil.

The Sand Creek Lateral, Irondale Gulch, and northwest drainages will be addressed together since they are similar. The Sand Creek Lateral drainage begins just west of Basin A and primarily slopes northwest, although there is a topographic high (Rattlesnake Hill) in the center. The eastern and northern boundaries of the Sand Creek Lateral drainage are defined by the surface drainage canal (NCSA-5d, NCSA-1f), which begins north of Seventh Avenue in Section 36 and extends through Section 35 before terminating in the northeast corner of Section 34. The surface drainage canal was dug in 1975 to divert South Plants runoff from Basin A. The Sand Creek Lateral marks the western boundary of the drainage basin. The Sand Creek Lateral is an irrigation ditch that was used before RMA activities began. It was later modified to carry South Plants runoff and liquid waste from West Plants complex operations to Basins D and E and, possibly during periods of heavy flow, toward or to First Creek. It was then used to transport Basin A overflow from Basin B to Basin C. Other hydrologic features in the drainage include the Basin A overflow ditches, Basin B, and the dry basin that was constructed to hold caustic aqueous wastes but never used.

The northwest drainage does not contain any basins or defined channels except for the Sand Creek Lateral, which forms its southeast border. The only significant hydrologic features are the numerous small topographic depressions that may collect runoff.

Since there are no defined stream channels in the northwest drainage or that portion of the Irondale Gulch drainage within the NCSA, overland flow and the collection of this flow in depressions are considered to be the primary surface water flow paths. The MKE recharge report considers the average recharge to groundwater from these areas to be 0.25 in/yr (MKE, 1988a).

The estimated 100 year flood discharge across the northwest boundary is 150 cfs (cubic feet per second), while the Standard Project Storm flood discharge is estimated at 4,100 cfs. The greater discharge value for the Standard Project Storm reflects the fact that projected infiltration and surface storage capacities would be slightly exceeded by the 100 year storm. Consequently, all additional precipitation during the Standard Project Storm would generate runoff (COE, 1983a/RIC 84066R01).

Where infiltration occurs below free-standing water, it is common for a low permeability zone to develop at the water/soil interface. This is due to the accumulation of interstitial silt and clay particles in the soil matrix. As a result, net infiltration into the vadose zone tends to be controlled by the flow through this low permeability zone of fine grained material. Due to the mechanics of flow in the vadose zone, the low permeability zone tends to be saturated where in contact with free water. Net infiltration below free-standing water bodies, therefore, can be predicted using Darcy's law and the value of saturated hydraulic conductivity that characterizes the low permeability zone. Increased local infiltration is considered a mechanism for groundwater recharge beneath the sewage treatment pond and along the Sand Creek Lateral and First Creek during extended periods of flow.

1.5.3 Unconfined Aquifer

The unconfined aquifer represents the uppermost water bearing unit at RMA. It is principally comprised of alluvium, although upper portions of the Denver Formation comprise part or all of the unconfined aquifer in places, particularly where bedrock crops out or where the overlying alluvium is unsaturated.

The alluvial component of the unconfined aquifer is composed predominantly of clay and silt deposits containing fine sands near the ground surface and grading with depth to coarser sands and sandy gravels. Regionally the alluvium is underlain by low permeability claystones or siltstones of the Denver Formation, but locally sandstone may subcrop (May 1982/RIC 82295R01).

The unconfined aquifer in the NCSA study area is generally heterogeneous. In some areas, the water table extends into the upper fine grained clay and silty sand layers of the alluvium. In other areas, it is within sandstones and weathered zones of the Denver Formation.

The bottom of the unconfined aquifer is defined as either the alluvium/bedrock contact where claystones of the Denver Formation subcrop, the base of the weathered zone within the Denver Formation where the overlying alluvium is unsaturated, or as being within sandstones of the Denver Formation in the areas where they subcrop beneath saturated alluvium.

In some areas fracturing within the upper portion of the Denver Formation provides a hydraulic connection with the alluvium, permitting these areas to behave as one hydrogeologic unit.

1.5.3.1 Lateral and Vertical Extent

The unconfined aquifer is generally defined laterally by the extent of saturated, unconsolidated deposits. The lateral extent of the alluvial component of the unconfined aquifer is interrupted in numerous areas where the top of the underlying Denver Formation extends above the water table, creating areas of unsaturated alluvium as shown on Plate NCSA 1.5-1. The unconsolidated deposits form a relatively continuous mantle over the Denver Formation as described in Section 1.4.2.

Vertically, the unconfined alluvial aquifer is defined as the saturated portion of the alluvial and Denver Formation units as defined above; the upper boundary corresponds to the water table, the lower to the alluvium/bedrock contact or the base of those portions of the Denver Formation in direct hydraulic connection with saturated alluvium or behaving with it as a hydrogeologic unit.

Unconfined aquifer thicknesses are greatest within the saturated alluvium in prominent paleochannels that are incised into the bedrock surface. These paleochannels, which strongly influence groundwater flow in the study area, show a preferential northwest direction (Figure NCSA 1.4-2).

Water Table

To characterize the general water table configuration across the study area, a water table map was constructed for the period April-June 1987 (Plate NCSA 1.5-1). The water table contour map was generated using the mean of water level elevations measured during this period in wells screened completely within alluvium, or across the alluvium/Denver Formation contact. The methodology used to create this map is discussed in greater detail in the

Water Remedial Investigation Report (EBASCO, 1989/RIC 89067R08). In some areas where the alluvium is designated as unsaturated, water levels in the underlying Denver Formation were found to be comparable to those in the surrounding saturated alluvium. Water table elevations in these areas are indicated as dashed lines.

Plate NCSA 1.5-1 indicates that primary lateral groundwater flow direction in the study area is toward the north and northwest, consistent with the overall flow direction for the unconfined aquifer at RMA (Figure NCSA 1.5-3). This water table contour map was used to assess magnitudes and directions of regional horizontal hydraulic gradients within the NCSA. The hydraulic gradient is defined as the change in total head with a change in distance measured perpendicular to the contour lines. Variations in hydraulic gradient magnitudes between areas are largely a function of alluvial saturated thickness, bedrock surface configurations, and hydraulic conductivities. Where alluvial saturated thicknesses are thin, hydraulic gradients tend to be influenced by the configuration of the bedrock surface. For example, where the bedrock surface slopes downward, the water table will follow the same downward trend.

Low gradients occur in paleochannels containing coarse sediments with high hydraulic conductivities. The lowest gradients in the NCSA occur west of "D" Street, between Basin F and the NBCS in the middle portion of Section 23. An average hydraulic gradient in this area was estimated to be 0.002; however, in localized zones, values may be as low as 3.5 ft per mile or 0.0007. In areas of greater saturated alluvial thickness (Plate NCSA 1.5-3), the bedrock surface exerts less influence on hydraulic gradients. In these areas, hydraulic gradients are largely controlled by hydraulic conductivity, with lower hydraulic gradients tending to occur within more permeable material. Examples of this are the low hydraulic gradients that occur in highly permeable gravels in the western portion of the study area in Sections 27 and 34. Average gradients were estimated to be 0.003 in these areas.

The steepest gradients in the area occur where groundwater is moving through less permeable alluvial material, through the Denver Formation underlying unsaturated alluvial areas, and where constriction of flow occurs. Examples of these conditions are the downgradient west side of the pilot portion of the NBCS, the upgradient area of the NWBCS, and the Basin A Neck paleochannel, respectively. Hydraulic gradients range from 0.02 to 0.04 in these areas.

Changes in gradient directions and magnitude are apparent in local areas such as:

- o Near paleochannels;
- o Near surface water features (i.e., North Bog, First Creek);
- o Within or adjacent to areas of unsaturated alluvium; and
- o Close to the boundary containment systems.

These deviations are generally the result of enhanced groundwater recharge/discharge below surface water features and refraction of groundwater flow lines at the boundaries between lithologic units with contrasting hydraulic conductivity (e.g., between alluvium and Denver Formation). Also, they are the result of the dewatering and recharge operations of the containment systems. The effects of the boundary containment systems will be discussed in Section 1.5.3.4. A detailed account of the changes in gradient directions and magnitude in the local areas mentioned above is presented in the and Water RI Report (Ebasco, 1989/RIC 89067R08).

The depth to water table in the NCSA is greatest beneath Rattlesnake Hill, along the eastern border with North Plants Study Area, and at the western border with the Western Study Area. In these regions depth to water table is typically greater than 40 feet, and reaches depths greater than 60 feet in places. Depth to water beneath the basins areas in Section 26 varies from 20 ft to nearly 50 ft. In contrast, the southeastern and northern parts of the study area are underlain by a water table at depths typically less than 20 feet, and beneath Basin A and in the NBCS areas, depth to water ranges from 0 to less than 10 feet. Plate NCSA 1.5-2 presents a generalized water table depth map for the study area.

Temporal Trends in the Unconfined Alluvial Aquifer

Historical fluctuations in the water table have been assessed by previous investigators (Smith, et.al., 1963/RIC 84324R02; Konikow, 1976/RIC 81266R33; Geraghty & Miller, 1979; Stollar & van der Leeden, 1981, RIC 81293R05; May, 1982/RIC 82295R01).

Historical water level fluctations have been large in the vicinity of Basin C. Fresh water was stored in the basin during the late 1950's. Water level data collected during 1957 (Smith, et al., 1963/RIC 84324R02) indicate that hydraulic heads beneath Basin C were 20 to 30 ft higher than present-day heads. Basin C also was used extensively for storage of fresh water from 1969 through 1975. Water level data for this period were not available. Water level data for the composite period 1955 through 1971 (Konikow, 1975/RIC 84324M01) show water-levels beneath the basin were approximately 10 ft higher than present-day water levels.

For the period from 1978 to 1981 overall water table elevation declined, generally on the order of 2 to 7 ft. Specifically, declining levels up to 7 ft were documented in Sections 23 and 24 south of the NBCS. Declining water table elevations were reported (1.1 to 2.4 ft) in the Basin A area during the same period (May, 1982/RIC 82295R01). However, for the period 1981 to 1987, the water table generally rose in the central and northwestern parts of the RMA, and declined near the boundary containment systems and Basin F (Ebasco, 1989/RIC 89067R08). These changes reflect a variety of factors, including irrigation and spraying practices, waste water discharges, operation of the boundary containment systems, and weather patterns.

Seasonal water table trends are reflective of differing amounts of recharge to and discharge from the alluvial aquifer. Generally, water table elevations vary seasonally with the highest water levels being recorded in the spring of each year and the lowest during the late summer or fall. This is shown in the seasonal hydrograph (Figure NCSA 1.5-4) constructed along an east-west line of wells located 1,100 ft upgradient of the NBCS. A detailed assessment of these trends is provided in Task 36 and Task 25 reports (ESE, 1988ss/RIC 88344R02; ESE, 1988tt/RIC 89024R02).

Saturated Alluvial Thickness

Saturated thickness varies with the bedrock topography. Plate NCSA 1.5-3 presents a contour map of saturated alluvial thickness for the NCSA. The water table map (Plate NCSA 1.5-1) and the bedrock contour map (Plate NCSA 1.4-3) were used to construct the saturated alluvial thickness map. Where bedrock highs exist, the saturated alluvium is quite thin or absent, and where paleochannels occur, saturated thicknesses can be as much as 35 ft. The most significant paleochannel in the NCSA is the Basin A Neck paleochannel, which extends from near the center of Basin A through Sections 36, 35, and 26 to termination in the northwest quarter of Section 27. Other prominent paleochannels lie in Sections 26, 25, 23, and 24 of the NCSA, which are probable remnants of an ancestral First Creek drainage. In the eastern portion of Sections 25 and 24, a thick saturated zone corresponds to the First Creek drainage paleochannel. This zone is up to 25 ft thick in Section 25. As it trends north toward NBCS, the maximum thickness decreases to 20 ft.

1.5.3.2 Aquifer Parameters

The following discussions pertain to the alluvial portion of the unconfined aquifer, the alluvial aquifer, and the confined Denver Formation zones.

In previous studies, the hydrogeologic properties, hydraulic conductivity, and storativity of the alluvial aquifer were determined by slug and pumping tests at various points in the NCSA (Zebell et al., 1979/RIC 81266R19; Mitchell, 1976/RIC 81281R04; May, 1982/RIC 82295R01; COE, 1983b/RIC 85176R01; Vispi, 1978 RIC/81266R70; Black & Veatch, 1980/RIC 81266R25). The locations of these tests are shown on Figure NCSA 1.5-5. A determination of the hydraulic conductivity of the aquifer is essential for determining flow rates and times of travel. Values of storativity are necessary for predicting water table fluctuations due to natural and manmade stresses.

Pumping test data indicate that the alluvial aquifer responds as an unconfined aquifer in most cases, but in some areas acts as an unconfined aquifer with a delayed yield. Test results indicate that, generally, the hydraulic conductivity of the alluvial aquifer ranges from 0.06 to 0.9 centimeters per second (cm/sec) (1.0×10^3 gpd/ft^2 to 2.0×10^4 gpd/ft^2). Table NCSA 1.5-1 summarizes alluvial aquifer pumping tests in the NCSA.

Values of hydraulic conductivity were also determined in the study area from slug tests. Hydraulic conductivity values derived from slug tests performed in the alluvial aquifer are more variable than hydraulic conductivity values derived from pumping tests. The values obtained by slug tests apply only to a relatively small area around the test well and may not represent conditions beyond the immediate borehole area. Fast recovery from slug tests performed may not have allowed for successful measurement in highly permeable materials. Table NCSA 1.5-2 summarizes alluvial aquifer slug tests in the NCSA.

There is general agreement between the mean hydraulic conductivity values obtained from pumping and slug-type aquifer tests, although several of the values obtained from slug tests seem to underestimate hydraulic conductivity. Values of hydraulic conductivity obtained from these slug tests ranged from 210 to 5,300 gpd/ft^2 (0.0099 to 0.25 cm/s), with a mean of 1,400 gpd/ft^2 (0.068 cm/s) (Zebell, 1979/RIC 81266R19). However, due to the variability of slug tests in the alluvial aquifer, it is preferable to rely on pumping test data for assessing the hydraulic conductivity of the alluvial aquifer.

Specific hydraulic conductivity values have been combined to define hydrogeologic units within the alluvial aquifer. These units, shown in Plate NCSA 1.5-4, generally correspond to the alluvial lithologic units described in Section 1.4.2. Each hydrogeologic unit has been assigned a representative and expected range of hydraulic conductivity values. A detailed discussion of the hydrogeologic units in the alluvial aquifer at RMA is presented in Section 2.4.1.3 of the Water RI Report (Ebasco, 1989/RIC 89067R08).

(ESE, 1988ss/RIC 88344R02). Surface water features locally influence the alluvial aquifer in the NCSA. These effects are primarily attributable to infiltration from surface water impoundments (the disposal basins) and stream/aquifer interactions.

First Creek is thought to have a significant influence on the alluvial aquifer. Evaluation of data collected over the past two years shows that, on the average, First Creek is losing water to the on-post alluvial aquifer. This assessment is somewhat complicated by the fact that during specific months of high precipitation, First Creek gains water along various on-post reaches. Gaining periods generally correspond to high precipitation periods during which surface runoff as well as elevated water tables contribute water to First Creek. Nevertheless, First Creek experiences an overall net loss of water to the alluvial aquifer in the NCSA (ESE, 1988ss/RIC 88344R02).

Recharge to the aquifer also results from the North Bog. Since 1982, the North Bog has received effluent from the NBCS and recharged water to the alluvial aquifer. The amount of water being recharged to the North Bog from October 1985 to May 1987 was estimated to be 117 gpm (ESE, 1988ss/RIC 88344R02). The water being recharged to the downgradient side of the barrier through the North Bog created high water table conditions beneath the east side of the NBCS. Also, higher hydraulic gradients are noticed in this area. As a result, the volume of effluent flow directed to the North Bog decreased in October 1983. Most NBCS effluent is now being recharged to the alluvial aquifer through a series of trenches.

Other surface water features in the NCSA infrequently contain water as discussed in Section 1.5.1, and they are considered less significant in terms of alluvial aquifer recharge.

1.5.4 Confined Denver Formation Aquifer

Regionally, the Denver Formation consists of a system of interbedded permeable and relatively impermeable sediments. Because of this, a high degree of variability in transmissivity and storativity values occur from one area to another. Groundwater flows laterally up-dip through sandstone lenses under confined conditions and discharges locally into the alluvial aquifer. The driving head for this up-dip flow results from the elevation difference between the recharge and discharge areas. Recharge occurs into outcropping Denver Formation sandstones at the margins of the Denver basin and at shallow subcrops.

One boring in the NCSA drilled near the North Boundary Containment System has penetrated the entire Denver Formation. Here, the Denver Formation consists of an approximately 250 to 300 ft thick series of carbonaceous clayshales, claystones, and siltstones (May et al., 1980/RIC 81266R48). These fine grained sediments are interbedded with weakly lithified, more permeable sandstone units. The sandstone units may be locally unconsolidated, but cementing with calcium carbonate, silica, or other minerals decreases the hydraulic conductivity of these sandstone units by two orders of magnitude or more (Ertec, 1981/RIC 81352R35). Where uncemented or partially cemented, these sandstone units are the dominant pathway for transmitting lateral groundwater flow through the Denver Formation.

At RMA, the water bearing sandstone units tend to be confined and heterogeneous, and where separated by confining zones, the upper units generally have a potentiometric surface 1 or 2 ft below the alluvial water table surface. In areas where Denver Formation sandstones subcrop into the alluvium, however, the water levels of the subcropping units are similar to that of the alluvial water table, indicating an area of potential discharge.

The following discussion of the Denver Formation hydrogeology in the NCSA focuses on aquifer recharge, groundwater movement, and aquifer discharge. The emphasis has been placed on describing the potentiometric surfaces and aquifer properties of Denver Formation zones. Several zones, separated by less permeable claystones and lignitic zones, have been identified at RMA. Zones A, 1U, 1, 2, 3, and 4 are most relevant to the NCSA.

1.5.4.1 Aquifer Recharge

In the NCSA there are three potential sources of natural recharge to the Denver Aquifer: direct infiltration of precipitation into small areas of outcropping Denver Formation sandstones in Sections 25 and 35; vertical percolation from saturated and unsaturated alluvium into underlying Denver units; and infiltration from surface water features. While regional flow within the Denver Formation zone may be updip, locally the potentiometric surface within upper parts of the Denver Formation may be below the water table surface. Therefore, the potential exists for recharge from the alluvial aquifer to the Denver Formation. This mode of recharge is a key factor in the interpretation of contaminant movement at RMA. The interaction between the alluvial aquifer and the Denver Formation is discussed in more detail in Section 1.5.5.

Although surface water features in the NCSA do not directly intersect the Denver Formation, recharge from the unlined basins may occur where Denver Formation sandstones are subcropping. Plate NCSA 1.4-4 depicts the Denver Formation units that subcrop to the alluvium in the NCSA. Denver zone A underlies Basin A and most of the lime settling basins area. Within zone A, the AS channel sand occurs beneath the western margin of Basin A and the Basin A Neck. A comparison of the estimated alluvial flow entering Basin A and the estimated alluvial flow exiting Basin A Neck has shown that groundwater losses of up to 40 percent may be occurring (RCI, 1982 and 1983). The alluvial losses may be attributable to discharge to the Denver Formation and, possibly, discharge to the central pool area within the basin to meet its evaporative demand. It should be noted that the variables used in this calculation and all calculations of this type are subject to interpretation and changes in groundwater conditions. In Section 26, the southern half of Basin C and portions of Basins D and E are underlain by Denver zone 1U. Zone 1 and an associated sandstone subcrop beneath Basins F, D, and E and in the northern half of Basin C. The sewage treatment plant and the North Bog (Section 24) are underlain by zone 2. The amount of recharge reaching the Denver Formation is difficult to quantify because of the variability in lithology and areal extent of each sandstone.

A significant means of recharge, in terms of contaminant migration, may result from activities of man. These activities, aside from the basins and surface impoundments mentioned above, include poor well construction, deteriorated wells, improper abandonment of wells, and excavation work that intercepts Denver Formation sandstones. In the areas adjacent to the North Boundary Containment System, recharge to the Denver Formation has resulted from the pumping of dewatering wells completed in the formation. These wells, in operation only during 1984, induced flow downward from the overlying alluvium.

1.5.4.2 Denver Formation Zones

In the NCSA, sandstones within six Denver Formation zones have been depicted in diagrammatic net sandstone isopach maps (Figures NCSA 1.4-4 through NCSA 1.4-9). The subdivision of the upper Denver Formation is based first on the geologic interpretation presented in Section 1.4.4; second on an assessment of hydrologic characteristics; and third on an assessment of contaminant distribution. Due to the regional description of these zones, they include varying amounts of permeable sandstone and less permeable siltstones and shales. The more permeable sandstone units vary in thickness and lateral extent within a particular regional zone.

1.5.4.3 Potentiometric Surface

Time-averaged potentiometric surface maps for Denver Formation zones A, 1U, 1, 2, 3, and 4 were constructed using water level data collected between 1981 and 1987. The potentiometric surface maps were evaluated to assess flow directions and hydraulic gradients within each regional zone.

The flow direction in zone A is generally northwest and north in Section 36 (Figure NCSA 1.5-6) and north to west in Section 35. The average hydraulic gradient in Zone A is 0.007 ft/ft.

The zone A subcrop limit is approximately beneath the northern edge of Sections 35 and 36 and along the western edge of Section 35.

The flow direction in zone 1U is to the west and northwest in Section 35 and in the southern part of Section 26 (Figure NCSA 1.5-7). Hydraulic gradients range from 0.006 in the southern portion of Section 35 to 0.015 ft/ft in the southern portion of Section 26. The limit of subcrop of the zone 1U is along a line trending northeast from the center of Section 34 through Basin C and into Section 25.

Flow directions within zone 1 are generally toward the northwest in the NCSA (Figure NCSA 1.5-8). The hydraulic gradient is about 0.006 ft/ft in the northern portion of Section 26 and the southern portion of Section 24 near the subcrop of zone 1. In Sections 35 and 36, the hydraulic gradient is about 0.01 ft/ft.

The generalized flow direction in zone 2 is west to northwest (Figure NCSA 1.5-9). The hydraulic gradient in Section 26 and the southern portion of Section 23 is approximately 0.005 ft/ft. In Section 35 and the eastern portion of Section 27, flow directions are to the west and the gradient is 0.01 ft/ft.

In zone 3, flow is almost due west along the northwest portion of RMA in Sections 22 and 27. Gradients range from 0.013 to 0.02 ft/ft in these sections. In Sections 23 and 24, where flow is to the northwest, gradients range from 0.003 to 0.01 ft/ft (Figure NCSA 1.5-10).

The deepest zone for which sufficient data were available to construct a map was zone 4. The potentiometric surface map of zone 4 indicates flow to the north in Section 24 and flow to the west-northwest in Sections 22, 23, 26, and 27 (Figure NCSA 1.5-11). Hydraulic gradients in this zone range from about 0.01 ft/ft in the northern area of Sections 22, 23, 24, and 26, and the northeast portion of Section 27, to 0.03 ft/ft in Section 34 and the southwest portion of Section 24. The flatter gradients in Sections 34 and 24 are indicative of the higher hydraulic conductivity associated with the sediments noted in those sections.

1.5.4.4 Aquifer Parameters

Hydraulic conductivity and storativity were determined from a large number of wells throughout the NCSA. Figure NCSA 1.5-12 shows the location of wells tested in the Denver Formation. Data from three pumping tests, two located in the NBCS area (Black & Veatch, 1980/RIC 81266R25) and one in the Basin A neck area (May et al., 1983), were available for evaluation in the NCSA. The pumping tests were conducted for periods of 28 hours to four days, and water level measurements were simultaneously taken in observation wells. The results are presented on Table NCSA 1.5-3. Pump tests were conducted in the As sand, and sands in zones 2 and 3. A range of hydraulic conductivity values resulted from the different units tested. The variations between, and the heterogeneous and anisotropic nature of the Denver Formation sandstones at RMA is thought to be responsible for the varying results. Hydraulic conductivities calculated from the pump tests showed a decrease with depth; the As sand had the highest K value tested, 7.7 ft/day, while the Zone 2 and Zone 3 sands tested at 1.6 and 1.1 ft/day, respectively. Because of the relatively few pump tests in the NCSA, results of slug tests are also considered in evaluating aquifer parameters of the Denver Formation.

Slug tests provide information on aquifer properties in the immediate vicinity of a borehole or well; however, when a large number of such tests are conducted in an area, data can be evaluated using statistical methods to determine the bulk properties of the system. Hydraulic conductivity results from the slug tests are presented graphically in a histogram shown on Figure NCSA 1.5-13. The histogram indicates that the log of K has an approximate bell-shaped curve, which is typical for point measurements of hydraulic conductivity in natural geologic media. For such distributions of hydraulic conductivity data, the geometric mean of the population is generally considered the best method for predicting a characteristic bulk value of conductivity.

The geometric mean of available Denver Formation hydraulic conductivity values is 0.37 feet per day (ft/day), or 1.3 X 10^{-4} cm/sec. The standard deviation of the logs for the sample population is approximately one order of magnitude. Given this standard deviation, 67 percent of the conductivity values would be expected to lie within the range of 1.3 X 10^{-5} and 1.3 X 10^{-3} cm/sec (0.037 ft/day to 3.7 ft/day). Values of hydraulic conductivity greater than 10^{-4} cm/sec are generally representative of sand materials, whereas values less than 10^{-4} cm/sec are typical for silt and silty sand.

Hydraulic Conductivity

The range of hydraulic conductivity values of Denver Formation zones is presented in Table NCSA 1.5-4. This table also shows the lithology of geologic materials within the screened interval. Values were acquired from slug tests unless otherwise indicated. Slug test results for Denver Formation units near the NBCS are presented in Table NCSA 1.5-5.

The significance of these K values is illustrated by examining flow rates based on the highest (worst-case) and lowest (best-case) K values. Lateral groundwater flow in high K sands, such as those that occur in zone 2 and exhibit a K of 34 ft/day, could be as high as 380 ft/yr. This was determined using Darcy's Law and a hydraulic gradient of 0.01 ft/ft and assuming a porosity of 0.33. Flow in lower K units such as zone 4 (K = 0.004 ft/day) may be as low as 0.04 ft/yr. It should be noted, however, that it is unlikely that groundwater will travel in one sandstone with the same hydraulic conductivity all the way from potential source areas to the RMA boundaries. This is due to the sandstones in the Denver Formation being discontinuous, heterogeneous, and anisotropic. Section 3.0 will further address the potential for contaminant migration in the Denver Formation. Neither of these flow rates addresses downward groundwater migration time between sand units. Vertical K is typically one to two orders of magnitude less than horizontal K. This indicates downward groundwater migration may be between 38 and 0.0004 ft/yr.

Storativity

Determination of aquifer storage coefficient on the basis of slug test data is generally of questionable reliability because of the curve matching process. Results from a pumping test conducted by May and others (1983) in the Basin A Neck area indicated a storativity of 0.065. This test was conducted in a sandstone with only 5 ft of weathered claystone bedrock between the alluvium and the top of the unit. Therefore, the results may reflect the influence of connection with the alluvium at this site. Storativity results from pumping tests conducted by Black and Veatch (1980/RIC 81266R25) in the north boundary area ranged from 0.0001 for Well 24154 to 0.0036 for Well 23176. These values are typical for confined aquifers.

1.5.4.5 Aquifer Discharge

In the NCSA, discharge from the Denver Formation to the alluvial aquifer occurs locally where Denver Formation sandstones are in direct contact with the alluvium. Areas where this may be occurring are discussed in the following section.

1.5.5 Aquifer Interactions

Local interactions between the alluvial and Denver Formation aquifers are means by which the Denver Formation can potentially become contaminated. Understanding the potential for intraformational, vertical groundwater movement between Denver Formation sandstone units is important for assessing the potential for vertical contaminant migration within the Denver Formation. Water level data obtained during investigations (Task 25, 36, and 44) have been used to assess the potential for flow between aquifers and are discussed in the following sections. These data are presented in the Task 25, Task 36, and WRIR Reports (ESE, 1988tt/RIC 89024R02; ESE, 1988ss/RIC 88344R02; Ebasco, 1989/RIC 89067R08).

In general, the regional flow pattern within the Denver Formation is updip towards the north and northwest under confined conditions. The upper part of the Denver Formation, however, may be hydraulically connected and behave with the alluvium as part of the unconfined aquifer. Factors influencing the discharge/recharge relationships between the Denver Formation and the alluvium include: the nature of the units in contact at the base of the alluvium, the degree of saturation of the contacting units, seasonal and local fluctuations in potentiometric surfaces for various units comprising the unconfined and the confined aquifers, fractures and jointing within the consolidated units, permeability contrasts in both vertical and lateral directions within and between contacting units, and unique local conditions such as the presence of standing water, drainage courses, wells, etc., in areas of interest.

1.5.5.1 Alluvial Aquifer and Denver Formation Sandstone Unit Interactions
The potential for vertical groundwater movement between the alluvial aquifer and the Denver Formation was assessed by evaluating the differences in water level elevations between wells at cluster sites measured during spring 1987. Lower water level elevations in wells screened within Denver Formation units, as compared to elevations in the alluvial aquifer, indicate a potential for the downward movement of water. Higher potentiometric levels in the Denver Formation units, as compared to elevations in the alluvial aquifer indicate a potential for upward movement.

Generally, alluvial and Denver Formation cluster wells located where Denver Formation sands subcrop have coincident water levels and gradients in similar directions, indicating flow from Denver Formation into the alluvium.

In the Basin A Neck area, downward vertical gradients have been noted between Wells 36112 and 36113 and Wells 35065 and 35066 (Plate NCSA 1.1-4) The vertical gradient at each of these sites was 0.01 ft/ft and 0.6 ft/ft, respectively.

Upgradient of the NBCS barrier, the water table elevation in the alluvial aquifer is higher than the potentiometric surface elevations of the upper units of the Denver Formation. Approximately 500 ft upgradient of the pilot portion of the soil-bentonite barrier the downward vertical gradient between the alluvial aquifer and the Denver Formation averages 0.07 ft/ft. Immediately upgradient of the pilot portion of the soil-bentonite barrier, a downward vertical gradient of approximately 0.12 ft/ft is observed at a cluster site near the barrier. These downward gradients could vary significantly near the soil-bentonite barrier due to higher alluvial water levels on the upgradient side and lower alluvial water levels on the downgradient side.

Immediately downgradient of the pilot portion of soil-bentonite barrier, the potentiometric surface of zone 2 begins to merge with the water table of the alluvial aquifer. In some instances, the zone 2 potentiometric surface appears to be coincident with the water table, and, in some cases, it appears to exhibit a higher potentiometric surface elevation. A higher potentiometric elevation in this unit may have been induced upgradient of the actual geologic subcrop of the unit due to low alluvial water-table conditions caused by inadequate NBCS recharge. However the potentiometric elevation is now expected to be declining as NBCS recharge has been improved by the recently-installed trenches.

Downgradient of the southwest end of the NWBCS, a downward gradient of 0.14 ft/ft occurs at Cluster Wells 22022 and 22023. South of the NWBCS in Section 27, a downward vertical gradient of 1.2 ft/ft occurs between Cluster Wells 27053 and 27054 (Plate NCSA 1.1-4).

1.5.5.2 Denver Formation Sandstone Unit Interactions

Although the zones within the Denver Formation are generally hydrologically and geologically distinct, they do interact in some locations at RMA. Areas of potential interaction were initially identified by comparison of potentiometric surface maps for each. Locations where sandstone units in different zones exhibited similar head values were identified as potential sites of sandstone interconnection.

Several parameters were assessed to determine aquifer interaction in the identified areas. These include: nature and thickness of the confining layer; physical interconnection of identified sand units; differential head and gradient between units; historical water levels; and further assessment and refinement based on potentiometric surface comparison. These areas of interaction are given in Table NCSA 1.5-5 with the interpreted physical setting listed.

In the NCSA, vertical gradients are generally downward between adjacent Denver Formation zones. This implies that groundwater within the upper Denver Formation sandstones in this area has the potential to flow to lower units before ultimately discharging to the alluvium near subcrop areas. This potential for vertical groundwater movement between Denver Formation sandstone units was assessed by evaluating differences in water elevations between clustered wells screened in adjacent sandstone units. These evaluations are discussed in greater detail in the Water Remedial Investigation Report (Ebasco, 1989/RIC 89067R08). Upward vertical gradients between units, while speculated to occur locally, have not been definitely located or determined.

In the Basin A Neck area, a downward vertical gradient of 1.0 ft/ft was observed between Wells 36113 and 36114, that were screened in zones 1u and 1, respectively. A downward vertical gradient was also observed between zones A1 and 1U in Section 35. A vertical gradient of 1.2 ft/ft exists between Wells 35062 and 35063.

Upgradient of the NBCS, vertical gradients are generally downward between adjacent Denver Formation sandstone units. Downward vertical gradients were observed between hydrostratigraphic zones 2 and 3 upgradient of the system. Approximately 500 ft upgradient of the soil-bentonite barrier, the downward vertical gradient between zones 2 and 3 is about 0.05 ft/ft.

About 350 ft downgradient of the soil-bentonite barrier and just west of "D" Street, a downward vertical gradient of 0.22 ft/ft was observed between Wells 23218 and 23219. These two wells were screened in zones 2 and 3, respectively.

Upgradient of the NWBCS, a net downward vertical gradient exists between Wells 23186 and 23817, which were screened in zones 2 and 4, respectively. There is no zone 3 screen in this cluster. A downward vertical gradient also exists between Wells 27060 and 27061, which were screened in zones 2 and 5, respectively. There is no zone 4 screen in this cluster. A slight downward vertical gradient of 0.02 ft/ft occurs between Wells 27057 and 27058. These wells were screened in zones 3 and 4, respectively.

Upgradient of the northeast end of the NWBCS, a downward vertical gradient of 0.35 ft/ft was measured between Wells 22030 and 22031. These wells were screened in zones 4 and 5, respectively. A downward vertical gradient of 0.23 ft/ft was also observed between Wells 22027 and 22028, which are upgradient of the NWBCS. These wells were screened in hydrostratigraphic zones 3 and 4, respectively. South of the NWBCS, a downward vertical gradient of 0.03 ft/ft was observed between Wells 27054 and 27055. These wells were screened in hydrostratigraphic zones 4 and 5, respectively.

Downgradient of the southwest end of the NWBCS, the water levels observed in Wells 22023 and 22024 appear to be coincident. These wells were screened in zones 4 and 5, respectively.

In summary, most areas investigated in the NCSA, particularly the NBCS and NWBCS areas, showed a downward migration potential for groundwater in the Denver Formation.

1.6 BIOTA

This section is an overview of information presented in the Biota RI Report (ESE, 1989/RIC 89054R01). Both terrestrial (vegetation and wildlife communities) and aquatic ecosystems were inventoried and characterized on a regional basis in studies conducted from 1985-1988. Biological samples were collected in order to measure any differences between biota at potentially contaminated areas and biota at control (nonsource) areas. Any effects in biota attributed to contamination sources at RMA are discussed in the Biota RI Report (ESE, 1989/RIC 89054R01).

A summary of the characteristics of the biota in the NCSA is included in this section. Species of interest that were sampled in the NCSA are presented in Section 2.0, along with contaminant levels detected in these samples. Each species' position in the food chain as it relates to potential contaminant migration pathways and bioaccumulation is detailed in Section 3.0.

1.6.1 Vegetation

The North Central Study Area contains a wide variety of major vegetation community types (Figure NCSA 1.6-1), including weedy forb, cheatgrass/perennial grass, cheatgrass/weedy forb, and areas replanted in crested wheatgrass. Yucca shrubland is a vegetation type considered minor over the rest of RMA but is the predominant cover over much of the hills near the northwestern border. Areas considered unvegetated within Basins A, C, and outside of Basin F may contain pioneering species such as sunflowers and morning glory at various locations.

Cottonwoods and ornamental trees (elms and russian olive trees) are distributed along the RMA borders, along section roads, and around the buildings of the NCSA. Wetlands and riparian habitat in the area include the North Bog and First Creek drainages in Section 24, and various drainage ditches in Sections 25, 26, 35, and 36.

Additional information on the vegetation community types across all of RMA, including unpublished data by Morrison-Knudsen Engineers, is summarized in the Biota RI Report (ESE, 1989/RIC 89054R01).

1.6.2 Terrestrial Wildlife

Wildlife abundance at RMA is related primarily to habitat quality and diversity, low levels of human disturbance, and the absence of hunting and livestock grazing. The great diversity of habitats on RMA provide cover, food, and reproductive habitat for many wildlife species, and in combination with the factors listed above, has led to wildlife populations for many species which are greater on RMA than in similar habitats off-site.

Because of the diversity of habitats in the NCSA, most of the wildlife species found on RMA are present here. A complete inventory of RMA wildlife species and details on their distribution in all study areas is found in the Biota RI Report (ESE, 1989/RIC 89054R01). The discussion below will detail the important wildlife species occurring in the NCSA.

1.6.2.1 Small Mammals

Black-tailed prairie dogs are the most conspicuous mammal on RMA, with extensive colonies covering approximately 5,000 acres (Clippinger, 1987). In the NCSA, prairie dog colonies cover large portions of Sections 22, 27, and 28 on the northwestern border of RMA, and local areas of Sections 23, 24, 25, 35, and 36 (Figure NCSA 1.6-2). Thirteen-lined and spotted ground squirrels, fox squirrels in riparian woodlands, and muskrats on the canals or First Creek are among the larger rodents inhabiting the NCSA. A great variety of smaller species including deer mice, plains harvest mice, western harvest mice, northern grasshopper mice, prairie moles, meadow voles, Ord's kangaroo rats, hispid pocket mice, and silky pocket mice occur here as well. Desert cottontails and black-tailed jackrabbits are abundant across most of RMA. In the NCSA, desert cottontails frequent the areas near prairie dog towns, while black-tailed jackrabbits seem to be most numerous in the yucca shrublands near the northwest border (Sections 22, 27, and 28), and in weedy areas throughout the study area. Eastern cottontails may occur in thickets and small riparian areas in the NCSA, while white-tailed jackrabbits have been reported only in small numbers over the entire area of RMA.

The small mammals are primary consumers (herbivores) in the food chain, and are preyed upon by coyotes, badgers, weasels, foxes, and raptors in the NCSA.

1.6.2.2 Deer

Both mule and white-tailed deer are common on RMA, including parts of the NCSA. Total counts for RMA made by the Colorado Division of Wildlife (CDOW) in December 1986 were 133 mule deer and 22 white-tailed deer. Total ground counts in 1986-87 by MKE produced numbers of 207 mule deer and 56 white-tailed deer. These numbers are high for the region, and both species are more abundant on RMA than at off-post comparison areas. Mule deer were most often observed around the basins (in Section 26) and in Sections 23 and 27 of the NCSA.

Deer are primary consumers (herbivores) in the food chain. The only possible predators for weakened or young deer in the NCSA are coyotes, but dead deer may be scavenged by any of the raptors or carnivores.

1.6.2.3 Carnivores

Coyotes are the largest and most conspicuous carnivores that inhabit RMA. The species is widespread on RMA and may most often be seen in or near prairie dog towns. Coyotes are relatively abundant on RMA compared to off-post locations. Coyotes range across all sections of the NCSA, but seem to avoid areas where human activity is high (e.g., Section 26, the Basin F Interim Response Action, and the Air Force station).

Badgers are also common on RMA and were observed in prairie dog towns of the NCSA during night surveys. The night spotting surveys for the endangered black-footed ferret yielded no sightings (ESE, 1987p/RIC 88194R02). Red fox, gray fox, and swift fox were observed during biota assessment studies in 1985 to 1987, but abundance data from the North Central Study Area were not collected (ESE, 1989/RIC 89054R01). Other carnivores present in the NCSA include raccoons, striped skunks, and long-tailed weasels.

Carnivores are at the third tropic level as secondary consumers. Coyotes are practically omnivorous, and will consume plants, insects, and a variety of vertebrates, including carrion. Badgers are more selective, feeding mostly on small mammals. Their diggings have been observed primarily in prairie dog colonies in the NCSA. Foxes, weasels, and skunks all prey upon a variety of small mammals, birds, and bird eggs, reptiles, and insects.

1.6.2.4 Raptors

RMA has a distinctively high density of raptors present on the installation. The abundance of prey, the distribution and abundance of suitable nesting and perching habitat, and the relative lack of human disturbance contribute to high population densities of hawks and owls. The NCSA includes habitat frequently used by raptors on RMA, including hawk roosts, raptor nests, raptor feeding locations, and bald eagle perches. Seventeen species of raptors were observed on RMA (including the NCSA) by biologists from ESE, U.S. Fish and Wildlife Service (USFWS), and MKE.

Recent winter raptor census work (ESE, 1988pp/RIC 88293R09) indicates that the ferruginous hawk is the most abundant wintering raptor on RMA.

Rough-legged hawks, Cooper's hawks, sharp-shinned hawks, red-tailed hawks, and golden eagles are also common at RMA during the winter. Wintering owls include long-eared, short-eared, barn, and great horned owls. During the summer, red-tailed hawks, Swainson's hawks, Northern harriers, and American kestrels are the common dominant breeders on RMA. Great-horned, long-eared, short-eared, and burrowing owls are common breeders as well.

Ferruginous hawks, eagles, and kestrels often concentrate near prairie dog towns and other habitats. Red-tailed and rough-legged hawks are most often found near woodlands and thickets, while owls are often observed near woodlands, riparian areas, and in buildings in the NCSA. The most evident exception among the owls are the burrowing owls, which nest exclusively in pre-existing burrows and cavities on or near the ground. Burrowing owls depend on prairie dog burrows for nesting habitat and have been observed in prairie dog colonies in the NCSA. Eagles roost in the Eastern Study Area, while hawk roosts were located in large trees across RMA.

Twenty-one raptor nests were located by ESE and MKE across RMA in 1986-1987. The locations of the nests in the NCSA are presented in Figure NCSA 1.6-2. The NCSA contains two of the raptor nests located, and ferruginous hawk communal roosts were observed in large trees. It is likely that some nests were missed, especially the long-eared owl and burrowing owl nests, which may be hidden in buildings and below ground, respectively.

Two species of Federal interest, the bald eagle (a Federally endangered species) and the ferruginous hawk (a species studied for listing by the USFWS) are present on RMA and the NCSA in large numbers during the winter months. More than 20 bald eagles roosted on RMA during the past two winters. Studies conducted by ESE indicate that bald eagles wintering on RMA feed primarily on prairie dogs and rabbits, many of which are stolen from ferruginous hawks. Bald eagle feeding and perching locations in the NCSA were observed in the winters of 1986-1988 (Figure NCSA 1.6-2). Eagle observations were particularly common around the prairie dog towns, which are important prey sources for all the raptors (ESE, 1988pp/RIC 88293R09). A complete explanation of study methods on the bald eagles of RMA, along

In addition to supporting the typical breeding songbirds of eastern Colorado, RMA (and the NCSA) supports breeding populations of several species that are more common on RMA than most eastern plains locations. A more detailed listing of the water birds, gulls, shorebirds, and songbirds, and their seasonal habitat use in the NCSA as well as the rest of RMA, is found in the Biota RI Report (ESE, 1989/RIC 89054R01).

1.6.2.6 Reptiles and Amphibians

The most conspicuous reptiles at RMA are the bullsnakes, which were frequently observed sunning themselves along roadways. Other snakes regularly encountered are the western hognose snake in sandy terrain, the common gartersnake and plains gartersnake near water, and the yellow-bellied racer in a variety of habitats. Plains rattlesnakes are commonly reported by various field personnel and have been observed in upland areas.

Probably the most abundant amphibian on RMA is the northern chorus frog. This frog species breeds in large numbers in most cattail stands and intermittent wet areas (such as the North Bog, First Creek, and the drainage ditches). Northern leopard frogs and tiger salamander larvae have been reported in the North Bog. The bull frog has been observed reqularly in the Lower Lakes, and could possibly occur at the North Bog. Woodhouses's toads, Great plains toads, and plains spadefoot toads are all occasionally seen as roadkills near the Lower Lakes. All three of these species have been heard calling from minor water bodies or intermittent wet areas on RMA, including the North Bog in the NCSA.

1.6.3 Aquatic Ecosystems

North Bog is the only permanent body of water in the NCSA. A description of North Bog contamination results from aquatic studies conducted during 1986 through 1988 by MKE is discussed in more detail in the RI for Biota (ESE, 1989/RIC 89054R01; MKE, 1988, personal communication). Among the data provided in the above documents are results of water quality, fish sizes, and fish condition index studies for both North Bog and the Lower Lakes, which are not included here.